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TESTS OF ROCK CORES, PEMBINE STUDY AREA, MICHIGAN AND WISCONSIN--ETC(U)
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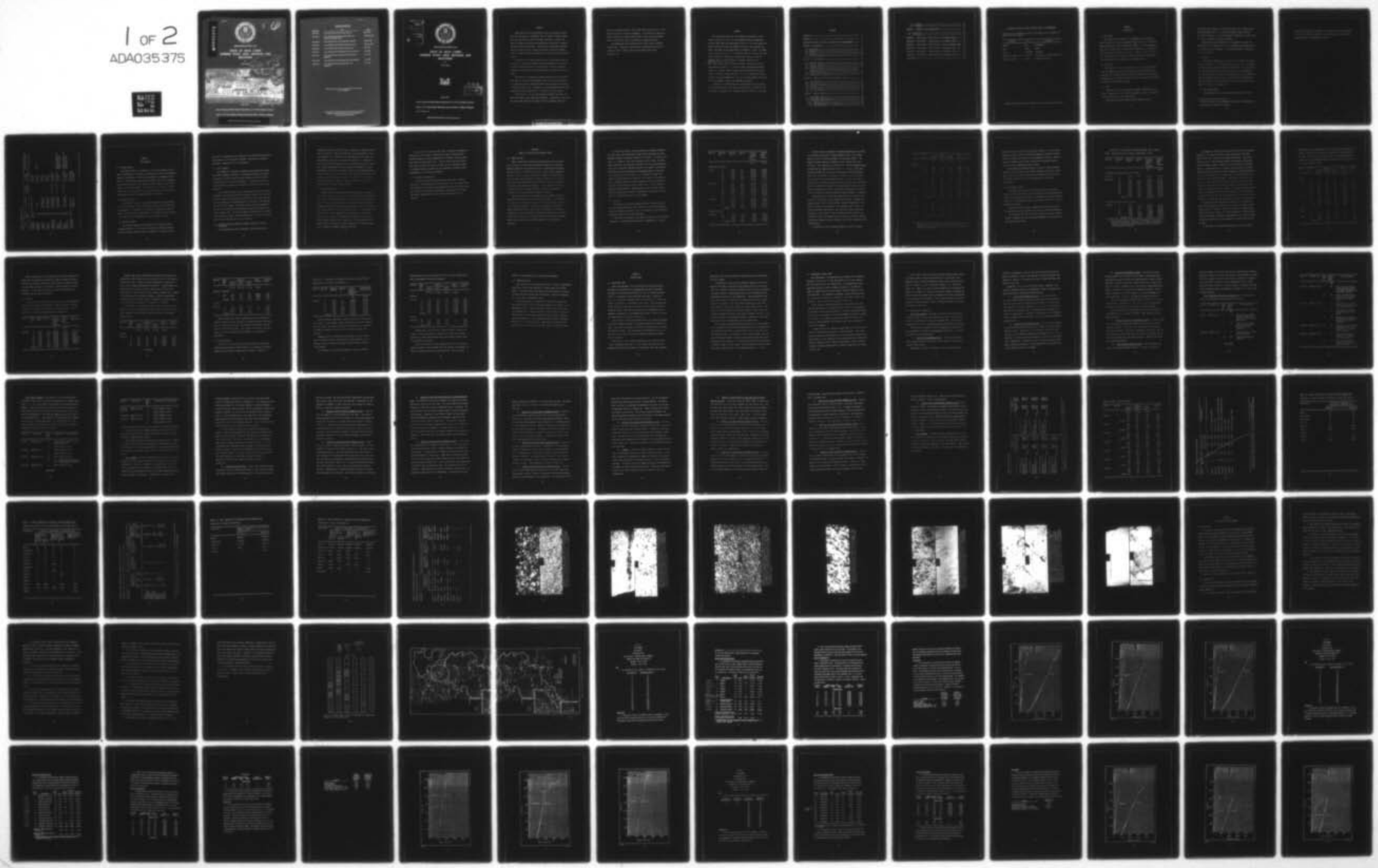

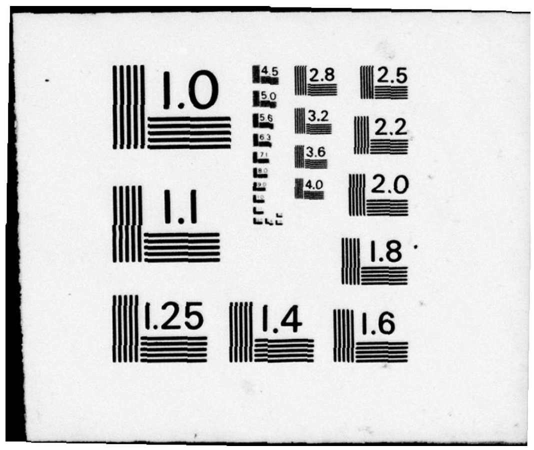
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MISCELLANEOUS PAPER C-70-14

TESTS OF ROCK CORES PEMBINE STUDY AREA, MICHIGAN AND WISCONSIN

by

R. W. Crisp

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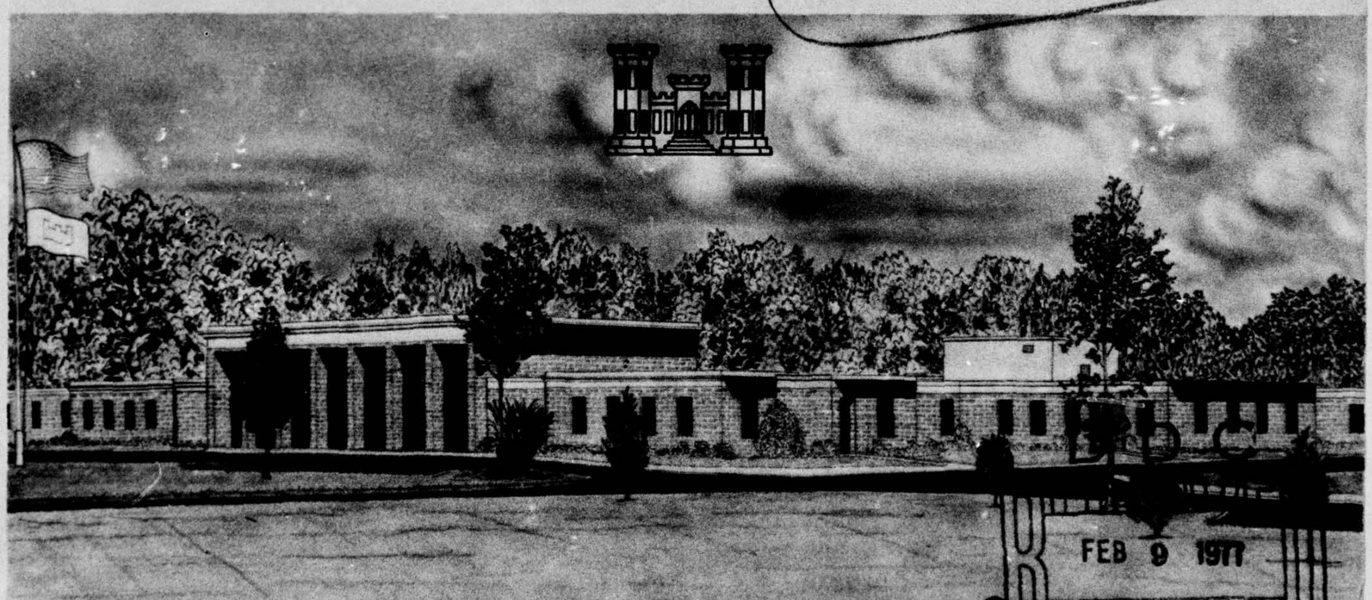

August 1970

Sponsored by Space and Missile Systems Organization, U. S. Air Force Systems Command

Conducted by U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

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ASSOCIATED REPORTS

Report No.	Title	Date
MP C-69-3	Tests of Rock Cores, Warren Area, Wyoming	March 1969
MP C-69-12	Tests of Rock Cores, Mountain Home, Idaho, and Fairchild, Washington, Areas	September 1969
MP C-69-16	Tests of Rock Cores, Castle Study Area, California	October 1969
MP C-70-4	Tests of Rock Cores, Bergstrom Study Area, Texas	February 1970
MP C-70-6	Tests of Rock Cores, Scott Study Area, Missouri	May 1970
MP C-70-7	Tests of Rock Cores, Plattsburgh Study Area, New York	June 1970
MP C-70-9	Tests of Rock Cores, Duluth-Vermillion Study Area, Minnesota	June 1970
MP C-70-10	Tests of Rock Cores, Michigamme Study Area, Michigan	June 1970
MP C-70-11	Tests of Rock Cores, Pease Study Area, New Hampshire	July 1970

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ABSTRACT

Laboratory tests were conducted on rock core samples received from six core holes in the Pembine Area of Dickinson County, Michigan, and Marinette and Oconto Counties, Wisconsin. Results were used to evaluate the quality and uniformity of the rock to depths of 200 feet below ground surface. The core was identified as predominantly tonalite, granite, amphibolite gneiss, and biotite gneiss, with relatively insignificant quantities of quartz gneiss and biotite schist.

Evaluation of the Pembine Area core on a hole-to-hole basis indicates that the granite removed from Hole PB-CR-20 and the biotite and quartz gneiss removed from Hole PB-CR-40 are quite competent materials and should offer good possibilities as competent hard rock media.

The tonalite and amphibolite gneiss removed from Hole PB-CR-27 were found to be relatively competent rock, with only one specimen, an amphibolite gneiss, yielding physical test results characteristic of marginal quality rock. Generally, this hole yielded material that should offer some possibility as a competent hard rock medium.

Holes PB-CR-2, -10, and -16A generally yielded rock core that exhibited rather varied physical properties. Though much of the rock was relatively competent in quality, several specimens that were

removed from depths greater than 50 feet below ground surface in each hole were found to be quite incompetent. The presence of these poor quality materials at depths greater than 50 feet dictates classification of the entire cores as unsuitable, incompetent media.

The evaluations and conclusions above were based on somewhat limited data. Therefore, more extensive investigation will be required in order to fully define the individual areas under consideration.

PREFACE

The study reported herein was conducted by personnel of the Concrete Division of the U. S. Army Engineer Waterways Experiment Station (WES) under the sponsorship of the U. S. Air Force Space and Missile Systems Organization (SAMSO) of the Air Force Systems Command. The study was coordinated with CPT Rupert G. Tart, Jr., SAMSO Project Officer, and Mr. M. V. Anthony of TRW, Inc., Norton Air Force Base, California. The work was accomplished during the period November 1969 to June 1970 under the general supervision of Mr. Bryant Mather, Chief, Concrete Division, and under the direct supervision of Messrs. J. M. Polatty, Chief, Engineering Mechanics Branch, W. O. Tynes, Chief, Concrete and Rock Properties Section, and K. L. Saucier, Project Officer. Mr. C. R. Hallford was responsible for the petrography work. Mr. R. W. Crisp performed the majority of the program analysis and prepared this report.

Directors of the WES during the investigation and the preparation and publication of this report were COL Levi A. Brown, CE, and COL Ernest D. Peixotto, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows.

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
pounds	0.45359237	kilograms
pounds per square inch	0.070307	kilograms per square centimeter
feet per second	0.3048	meters per second

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The purpose of this study was to supplement the information being obtained for the area evaluation study by the U. S. Air Force Space and Missile Systems Organization (SAMSO). It was necessary to determine the properties of the specific materials for an analysis of the quality and uniformity of the rock. Results of tests on cores from the Pembine Area of Dickinson County, Michigan, and Marinette and Oconto Counties in Wisconsin are reported herein.

1.2 OBJECTIVE

The objective of this investigation was to conduct laboratory tests on samples from areas containing hard, near-surface rock to determine the integrity and the mechanical behavior of the materials as completely as possible, analyze the data thus obtained, and report the results to appropriate parties.

1.3 SCOPE

Laboratory tests were conducted on samples received from the field as indicated in the following paragraph. Table 1.1 gives pertinent information on the various tests.

Tests were conducted to determine the general quality,

uniformity, and integrity of the rock from the area. Physical properties determined were: (1) relative hardness (Schmidt number), (2) specific gravity, (3) ultimate uniaxial compressive strength, and (4) static and dynamic elastic properties.

Special tests were conducted to (1) determine the degree of anisotropy of the sampled rock, and (2) determine and compare direct and indirect tensile strengths. A limited petrographic examination was also performed.

1.4 SAMPLES

Samples were received from six holes in the Pembine Area designated as PB-CR-2, -10, -16 and -16A, -20, -27, and -40. All samples were NX-size cores (nominal 2-1/8-inch[1] diameter). Test specimens of the required dimensions, as given in Table 1.1, were prepared for the individual tests. Quality and uniformity tests were conducted on selected specimens from all holes. Special tests were conducted on specimens selected from the various core holes to represent differences in rock type, weathering, etc.

1.5 REPORT REQUIREMENTS

The immediate need for the test results required that data

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[1] A table of factors for converting British units of measurement to metric units is presented on page 8.

reports be compiled and forwarded to the users as work was completed on each hole. The data reports of the individual test results are included herein as Appendixes A through F.

TABLE 1.1 SUMMARY OF TESTS

Test	Specimen Size	Test Equipment	Recording Equipment	Measured Properties	Computed Properties
Relative hardness	1 diam by 2 diam	Schmidt hammer	--	Relative hardness	--
Specific gravity		Scales	--	Specific gravity	Density
Indirect tension		440,000-pound test machine	--	Tensile strength	--
Direct tension		30,000-pound test machine	--	Tensile strength	--
Unconfined compression		440,000-pound test machine	X-Y recorder	Compressive strength	--
Static elastic properties		440,000-pound test machine	X-Y recorder	Compressive strength	Young's, shear, and bulk moduli and Poisson's ratio
Dynamic elastic properties		Pulse generator, amplifiers	Oscilloscope	Compressional and shear velocities	Young's, shear, and bulk moduli and Poisson's ratio
Petrographic examination	Variable	Microscopes, X-ray diffraction	--	Appearance, texture, and mineralogy	--

CHAPTER 2

TEST METHODS

2.1 SCHMIDT NUMBER

The Schmidt number is a measure of the relative degree of hardness as determined by the degree of rebound of a small mass propelled against a test surface. The test was conducted as suggested in Reference 1 (a Swiss-made hammer was used) except that 8 to 12 readings per specimen were made. The average of these readings is the Schmidt number, or relative hardness. The hardness is often taken as an approximation of rock quality and may be correlated with other physical characteristics such as strength, density, and modulus.

2.2 SPECIFIC GRAVITY

The specific gravity of the as-received samples was determined by the loss-of-weight method conducted according to Method CRD-C 107 of Reference 2. A pycnometer is utilized to determine the loss of weight of the sample upon submergence. The specific gravity is equal to the weight in air divided by the loss of weight in water.

2.3 INDIRECT TENSION

The tensile strength was determined by the indirect method, commonly referred to as the tensile splitting or Brazilian method, in which a tensile failure stress is induced in a cylindrical test

specimen by a compressive force applied on two diametrically opposite line elements of the cylindrical surface. The test was conducted according to Method CRD-C 77 of Reference 2.

2.4 DIRECT TENSION

For purposes of comparison, specimens were prepared and tested for tensile strength according to the American Society for Testing and Materials (ASTM) proposed "Standard Method of Test for Direct Tensile Strength of Rock Core Specimens." Tensile splitting tests were conducted on specimens cut adjacent to the direct tensile test specimens.

For the direct tension tests, the specimens were right circular cylinders, the sides of which were straight to within 0.01 inch over the full length of the specimen and the ends of which were parallel and not departing from perpendicularity to the axis of the specimen by more than 0.25 degree. Cylindrical metal caps were cemented to the ends of the specimens and provided the means for applying the direct tensile load. The load was applied continuously by a 30,000-pound-capacity universal testing machine and at a constant rate such that failure occurred within 5 to 15 minutes.

2.5 ULTIMATE UNIAXIAL COMPRESSIVE STRENGTH AND STATIC ELASTIC PROPERTIES

The unconfined and cyclic compression test specimens were

prepared according to ASTM and Corps of Engineers standard method of test for triaxial strength of undrained rock core specimens, CRD-C 147 (Reference 2). Essentially, the specimens were cut with a diamond blade saw, and the cut surfaces were ground to a tolerance of 0.001 inch across any diameter with a surface grinder prior to testing. Electrical-resistance strain gages were utilized for strain measurements, two each in the axial (vertical) and horizontal (diametral) directions. Static Young's, bulk, and shear moduli were computed from strain measurements taken at 50 percent of the ultimate uniaxial compressive strength. Stress was applied with a 440,000-pound-capacity universal testing machine.

2.6 DYNAMIC PROPERTIES

Compressional and shear wave velocities, dynamic bulk, shear, and Young's moduli, and Poisson's ratio were determined according to the proposed ASTM "Standard Method of Test for Laboratory Determination of Ultrasonic Pulse Velocities and Elastic Constants of Rock." The method consisted essentially of generating a wave in the specimen with a pulse generator unit and measuring, with an oscilloscope, the time required for the compression and shear waves to travel the length of the specimen, the resulting wave velocity being the distance traveled divided by the travel time. These compressive and shear velocities, along with the bulk density of the specimen, were used to compute the dynamic elastic properties.

In the case of the special tests used to determine the degree of anisotropy of the samples, compression and shear velocities were measured along two mutually perpendicular, diametral (lateral) axes and along the longitudinal axis. This was facilitated by grinding four 1/2-inch-wide strips down the sides of the cylindrical surface at 90-degree angles and generating the compressive and shear waves perpendicular to these ground surfaces.

2.7 PETROGRAPHIC EXAMINATION

A limited petrographic examination was conducted on samples selected to be representative of the material from the several holes. The examination was limited to identifying the rock, determining general condition, identifying mineralogical constituents, and noting any unusual characteristics that may have influenced the test results.

CHAPTER 3

RESULTS OF QUALITY AND UNIFORMITY TESTS

3.1 TESTS UTILIZED

Based on experience accumulated through testing and data analysis of core from study areas previously evaluated, the following physical properties were selected for use in evaluating the quality and uniformity of the Pembine rock core: Schmidt number, specific gravity, ultimate uniaxial compressive strength, and compressional wave velocity. Dynamic elastic constants determined for all specimens tested were compared with static elastic constants determined for selected representative specimens. Static moduli were based on a Poisson's ratio and tangent modulus of elasticity computed at 50 percent of ultimate uniaxial compressive strength.

The core received from the Pembine Area was somewhat varied in composition and comprised four principal rock types: (1) tonalite, (2) granite, (3) amphibolite gneiss, and (4) biotite gneiss. Tonalite was the most abundant. Relatively insignificant quantities of quartz gneiss and biotite schist were also received from the area. Differences in ultimate uniaxial compressive strength appear to have arisen from variation in rock type coupled with variation in nature, number, and inclination of fractures present in the individual specimens.

To facilitate analysis, data were generally grouped according to rock type, and, where applicable, these general groupings were subdivided according to physical conditions as follows: (1) intact rock core, i.e., material free from macroscopic joints, seams, vesicles, and/or fractures; (2) moderately fractured rock core containing horizontally or vertically oriented fractures; (3) highly to critically fractured rock core containing well developed systems of fracture, or critically oriented fractures, i.e., fractures inclined with respect to the horizontal at angles so as to result in the development of shearing stresses of failure magnitude when the specimen is subjected to relatively low axial stress; and (4) rock containing calcite-filled fractures. Detailed physical test results are presented in Appendixes A through F; summaries of the results are tabulated in the various sections of this chapter.

3.2 TONALITE

The majority of the core received from Hole PB-CR-10 and portions of that received from Holes PB-CR-2 and -27 were petrographically identified as tonalite. Most of the specimens were moderately fractured; several were highly fractured.

A summary of the physical test results is given in the following tabulation. Detailed results are given in Appendixes A, B, and E.

Hole No.	Specimen No.	Specific Gravity	Schmidt No.	Ultimate Uniaxial Compres-sive Strength	Compres-sional Wave Velocity
				psi	ft/sec
Moderately Fractured:					
PB-CR-2	3	2.68	--	37,120	16,270
	5	2.72	50.6	18,790	18,760
	9	2.67	--	16,170	16,440
	12	2.68	--	23,290	16,200
	19	2.69	56.5	27,880	15,220
	23	2.68	53.9	25,450	15,210
	25	2.66	55.5	32,580	15,830
PB-CR-10	3	2.72	53.7	18,760	19,890
	5	2.74	55.9	14,210	20,050
	8	2.70	52.2	11,150	19,470
	14	2.71	54.8	11,420	19,430
	19	2.74	--	13,730	19,420
	22	2.71	--	15,850	19,060
	23	2.70	52.8	14,670	19,200
	24	2.73	48.5	19,940	19,920
PB-CR-27	5	2.75	54.6	25,610	18,860
	8	2.74	--	28,480	19,220
	12	2.76	--	36,970	18,830
	20	2.67	--	25,000	17,460
	Average	2.71	53.5	21,950	18,140
Highly Fractured:					
PB-CR-10	10	2.69	--	7,880	17,580
	12	2.65	56.8	5,300	17,670
	17	2.70	--	6,730	18,050
	Average	2.68	56.8	6,640	17,770

Ultimate uniaxial compressive strengths exhibited by the tonalite specimens were rather variable, apparently due to the rather large variation in nature and degree of fracturing present. The highly fractured specimens yielded ultimate strengths less than 8,000 psi. The moderately fractured core exhibited strengths ranging in magnitude from approximately 11,000 to 37,000 psi. This large range of strength for the group of moderately fractured specimens would seem to indicate the presence of another important variable, but one which was not immediately obvious. The fact that range in strength (for a particular grouping) generally decreased substantially when the physical test results of the moderately fractured core were further subdivided according to hole number reinforces this conclusion, the additional variable apparently being dependent on locality.

Compressional wave velocities exhibited by the tonalites were much less varied than ultimate compressive strengths, ranging from approximately 15,000 to 20,000 ft/sec. Relative magnitudes of this physical property also appeared to be dependent upon locality, as scatter decreased significantly when data were further subdivided according to hole number. Nature and degree of fracturing had no discernible effect on compressional wave velocity; ultimate uniaxial compressive strength showed no definite trend toward correlation with this property.

As indicated in the following tabulation, elastic constants

Hole No.	Specimen No.	Modulus			Shear Velocity	Poisson's Ratio
		Young's	Bulk	Shear		
		10^6 psi	10^6 psi	10^6 psi	ft/sec	
Dynamic:						
PB-CR-2	3	9.4	2.7	5.2	11,950	a
	5	7.8	9.0	2.9	8,890	0.36
	9	7.4	5.9	2.8	8,890	0.29
	12	7.8	5.3	3.1	9,290	0.26
	19	7.2	4.5	2.9	8,960	0.23
	23	6.9	4.7	2.8	8,750	0.25
	25	7.1	5.2	2.8	8,830	0.27
PB-CR-10	3	9.4	9.8	3.5	9,790	0.34
	5	10.7	9.3	4.1	10.570	0.31
	8	7.0	10.4	2.5	8,300	0.39
	14	7.1	10.3	2.6	8,370	0.39
	19	8.1	9.9	3.0	8,990	0.36
	22	7.4	9.7	2.7	8,580	0.37
	23	10.1	8.2	3.9	10,370	0.29
	24	7.2	11.1	2.6	8,360	0.39
PB-CR-27	5	7.9	9.3	2.9	8,870	0.36
	8	7.3	7.3	2.6	8,470	0.38
	12	7.9	7.9	2.9	8,830	0.36
	20	5.6	8.2	2.0	7,520	0.39
	Average	7.9	7.8	3.0	9,080	0.33
Static:						
PB-CR-2	3	10.0	5.2	4.2	--	0.18
	25	9.8	5.3	4.1	--	0.19
PB-CR-10	5	11.1	7.4	4.4	--	0.25
	19	11.8	6.4	4.9	--	0.19
	23	10.0	5.7	4.1	--	0.21
PB-CR-27	12	11.4	8.0	4.5	--	0.26
	Average	10.7	6.3	4.4		0.21

[a] Dynamic Poisson's ratio could not be accurately computed for specimen PB-CR-2-3 due to the unrealistically high ratio of shear wave velocity to compressional wave velocity.

determined for the tonalite were generally uniform. As with the compressional wave velocities previously discussed, correlation between ultimate strength and modulus was not immediately obvious. However, values of dynamic Young's modulus consistently appeared slightly lower than the corresponding static values.

Stress-strain curves determined for several of these specimens revealed that the tonalite was slightly inelastic and rather brittle. Upon cycling, the tonalite specimens tested herein generally exhibited slight hysteresis, and strain appeared to be completely recoverable.

3.3 AMPHIBOLITE GNEISS

The entire core received from Holes PB-CR-16 and -16A and a portion of the core received from Hole PB-CR-27 were petrographically identified as amphibolite gneiss. All specimens contained fractures; fractures in the specimens received from Holes PB-CR-16 and -16A were sealed with calcite.

Values of ultimate uniaxial compressive strength exhibited by the amphibolite gneiss specimens from this area ranged considerably.

The specimens containing fractures sealed with calcite yielded ultimate strengths that had no apparent dependence on orientation of the respective fractures.

A summary of the results of physical property tests is given below. Detailed results are given in Appendixes C and E.

Hole No.	Specimen No.	Specific Gravity	Schmidt No.	Ultimate Uniaxial Compressive Strength	Compressional Wave Velocity
				psi	ft/sec
Containing Fractures Sealed with Calcite:					
PB-CR-16	3	2.80	32.7	11,790	18,960
PB-CR-16A	1A	2.89	--	27,270	20,690
	5A	2.94	57.8	12,420	22,180
	6A	2.87	56.0	6,820	21,750
	8A	2.95	57.0	21,910	22,500
	10A	2.93	52.9	24,240	22,180
	11A	2.81	48.6	14,820	21,240
	13A	2.85	56.4	5,790	21,670
	16A	2.86	51.4	17,210	21,520
	19A	2.85	48.3	8,300	20,770
	Average	2.88	51.2	5,790 to 27,270[a]	21,450
Containing Fractures with No Calcite:					
PB-CR-27	1	2.92	57.3	43,030	20,460
	4	2.89	--	21,210	20,950
	7	2.90	51.7	31,210	20,620
	13	2.83	--	27,120	19,510
	17	2.91	52.1	36,360	20,820
	19	2.92[b]	60.0[b]	3,330[b]	21,320[b]
	Average	2.89	53.7	31,790	20,470

[a] Due to large variation, range is given rather than average.
[b] Critically fractured; therefore, not included in average. Remainder of amphibolite gneiss specimens from Hole PB-CR-27 were moderately fractured.

The amphibolite gneiss tested from Hole PB-CR-27 also contained fractures, but, unlike fractures in the cores tested from Holes PB-CR-16 and -16A, they were not sealed with calcite. This difference in nature of the fractures present was apparently responsible for the somewhat different behavior of the two groups of specimens tested. The specimens that contained no calcite along the fracture surfaces exhibited ultimate uniaxial compressive strengths generally of greater magnitude and less range than those characteristic of the core with calcite-sealed fractures. The specimen containing critically oriented calcite-free fractures was predictably quite weak, unlike the specimens with critically oriented calcite-sealed fractures, which exhibited erratic results. The logical conclusion here is that the presence of calcite on the fractures in the specimens from Holes PB-CR-16 and -16A was responsible for the generally lower strengths and rather erratic responses to testing of this material.

Compressional wave velocities determined for the amphibolite gneiss were apparently unaffected by the nature and degree of fracturing present in the core. While some variation in compressional wave velocities was evident, it was not excessive. Unlike ultimate uniaxial compressive strengths, compressional wave velocities showed no apparent connection with the presence of calcite along fracture surfaces.

As indicated in the following tabulation, elastic constants

determined for this material were rather uniform and quite high, apparently unaffected by the nature and degree of fracturing present in the core. Moreover, static Young's moduli were generally slightly higher than the corresponding dynamic values, while static Poisson's ratios were somewhat lower.

Hole No.	Specimen No.	Modulus			Shear Velocity	Poisson's Ratio
		Young's	Bulk	Shear		
		10^6 psi	10^6 psi	10^6 psi	ft/sec	
Dynamic:						
PB-CR-16	3	9.0	9.1	3.4	9,460	0.33
PB-CR-16A	1A	10.5	11.4	3.9	10,040	0.35
	5A	12.6	13.2	4.7	10,930	0.34
	6A	12.1	12.2	5.6	10,840	0.33
	8A	13.0	13.7	4.9	11,050	0.34
	10A	12.9	12.9	4.8	11,090	0.33
	11A	10.9	11.6	4.1	11,380	0.34
	13A	11.6	12.2	4.3	10,620	0.34
	16A	11.7	11.9	4.4	10,700	0.33
	19A	11.2	10.8	4.2	10,530	0.33
PB-CR-27	1	12.2	10.1	4.7	10,960	0.30
	4	11.3	11.4	4.2	10,440	0.33
	7	9.9	9.9	3.6	9,650	0.36
	13	8.8	10.6	3.3	9,250	0.36
	17	11.9	10.9	4.5	10,740	0.32
	19	12.8	11.3	4.9	11,140	0.31
	Average	11.4	11.4	4.3	10,550	0.33
Static:						
PB-CR-16A	1A	11.8	8.9	4.6	--	0.28
	8A	14.3	10.3	5.6	--	0.27
	19A	8.2	5.4	3.3	--	0.25
PB-CR-27	4	13.5	9.5	5.3	--	0.26
	17	13.9	9.5	5.5	--	0.26
	Average	12.3	8.7	4.9		0.26

Cyclic stress-strain curves determined for several specimens revealed that the amphibolite gneiss was slightly inelastic and somewhat brittle, generally exhibiting little plastic deformation prior to catastrophic failure. Upon cycling, some hysteresis was usually detected. In most instances, however, strain was completely recoverable when the load was removed.

3.4 GRANITE

The entire core received from Hole PB-CR-20 was petrographically identified as medium-grained granite. Several specimens contained fractures. A summary of the results of physical property tests is given below. Detailed results are given in Appendix D.

Hole No.	Specimen No.	Specific Gravity	Schmidt No.	Ultimate Uniaxial Compressive Strength	Compressional Wave Velocity	Core Description
				psi	ft/sec	
PB-CR-20	2	2.68	55.2	24,240	16,610	Fractured
	4	2.68	51.0	38,180	16,990	Intact
	7	2.66	59.3	31,820	17,200	Intact
	10	2.66	59.4	31,670	17,730	Intact
	14	2.70	--	33,330	17,350	Fractured
	17	2.70	55.3	38,480	17,290	Intact
	19	2.65	--	32,730	17,720	Fractured
	21	2.66	57.6	33,030	17,560	Intact
	Average	2.67	56.3	32,940	17,310	

Physical test results exhibited by the granite from this area revealed that this material was very uniform in spite of the presence of some fracturing. Ultimate uniaxial compressive strengths were rather high, averaging approximately 33,000 psi. Compressional wave velocities were also quite uniform, ranging only from 16,610 to 17,730 ft/sec. These velocities were, however, somewhat low in light of the relatively high ultimate strengths. Neither compressional wave velocities nor ultimate uniaxial compressive strengths appeared to be significantly affected by the presence of fractures.

As indicated in the tabulation below, elastic constants determined for the granite specimens were also rather uniform, with static moduli generally running slightly higher than their corresponding dynamic values.

Hole No.	Specimen No.	Modulus			Shear Velocity	Poisson's Ratio
		Young's	Bulk	Shear		
		10^6 psi	10^6 psi	10^6 psi	ft/sec	
Dynamic:						
PB-CR-20	2	5.9	7.1	2.2	7,750	0.36
	4	7.8	6.4	3.0	9,120	0.30
	7	7.9	6.5	3.0	9,220	0.30
	10	6.8	7.9	2.5	8,350	0.36
	14	8.8	6.3	3.5	9,790	0.27
	17	8.3	6.6	3.2	9,420	0.29

(Continued)

Hole No.	Specimen No.	Modulus			Shear Velocity	Poisson's Ratio
		Young's	Bulk	Shear		
		10^6 psi	10^6 psi	10^6 psi	ft/sec	
Dynamic (Continued):						
	19	6.6	8.0	2.4	8,260	0.36
	21	6.4	7.9	2.3	8,090	0.37
	Average	7.3	7.1	2.8	8,750	0.33
Static:						
PB-CR-20	2	9.6	5.4	4.0	--	0.21
	4	9.8	5.3	4.1	--	0.19
	21	13.9	8.5	5.6	--	0.23
	Average	11.1	6.4	4.6		0.21

Cyclic stress-strain curves determined for three specimens of granite revealed that this material was somewhat inelastic and rather brittle, exhibiting relatively little plastic deformation (axially) prior to catastrophic failure. This material did exhibit some hysteresis, but upon unloading, strain appeared to be completely recoverable.

3.5 BIOTITE GNEISS

Portions of the core received from Hole PB-CR-40 were petrographically identified as biotite gneiss. All specimens contained tightly closed fractures ranging from horizontal to vertical in

orientation. A tabulation of physical test results is given below. Detailed results are given in Appendix F.

Hole No.	Specimen No.	Specific Gravity	Schmidt No.	Ultimate Uniaxial Compressive Strength	Compressional Wave Velocity
				psi	ft/sec
PB-CR-40	4	2.73	--	36,890	18,270
	7	2.75	54.6	27,270	19,710
	11	2.76	--	25,390	17,910
	12	2.74	--	24,700	19,120
	15	2.92	54.9	56,670	22,340
	20	2.74	56.0	42,120	19,230
	21	2.75	58.5	24,090	18,900
	Average	2.77	56.0	33,880	19,250

Ultimate uniaxial compressive strengths exhibited by the biotite gneiss were, on the average, higher than those for any other material from this area. The range in strength was probably due to variation in nature and degree of fracturing, but no definite trends were apparent.

Compressional wave velocities were moderate to high in magnitude, the highest velocity (22,340 ft/sec) being exhibited by the specimen that also yielded the highest ultimate uniaxial compressive strength.

As indicated in the following tabulation, elastic constants

determined for the biotite gneiss from this area were somewhat variable, particularly the dynamic constants.

Hole No.	Specimen No.	Modulus Young's	Modulus Bulk	Modulus Shear	Shear Velocity	Poisson's Ratio
		10^6 psi	10^6 psi	10^6 psi	ft/sec	
Dynamic:						
PB-CR-40	4	7.5	8.6	2.8	8,670	0.35
	7	10.5	9.0	4.0	10,440	0.30
	11	7.8	8.0	2.9	8,870	0.34
	12	10.5	8.0	4.1	10,570	0.28
	15	13.2	13.0	5.0	11,240	0.33
	20	8.1	9.6	3.0	8,990	0.36
	21	10.0	8.0	3.9	10,260	0.29
	Average	9.7	9.2	3.8	9,860	0.32
Static:						
PB-CR-40	12	11.8	7.2	4.8	--	0.23
	20	14.5	9.3	5.9	--	0.24
	Average	13.2	8.2	5.4		0.24

Interestingly, the variation in dynamic elastic constants appeared to be due principally to variation in shear wave velocity. There was no trend toward higher moduli with higher ultimate uniaxial compressive strengths.

Cyclic stress-strain curves determined for two of the biotite gneiss specimens tested revealed that this material was somewhat inelastic, generally exhibiting some hysteresis. Upon unloading,

however, strain appeared to be completely recoverable.

3.6 OTHER ROCK TYPES

Also received from the Pembine Area, but in rather insignificant quantities, were several specimens of quartz gneiss and biotite schist. The quartz gneiss was removed from Hole PB-CR-40, and the biotite schist was removed from Hole PB-CR-2. Results of physical tests are given in Appendixes A and F.

The quartz gneiss was comparable to the biotite gneiss also removed from Hole PB-CR-40, exhibiting physical test results in the same general range. The biotite schist removed from Hole PB-CR-2 was determined to be somewhat weaker than the tonalite removed from the same hole. The two tonalite-biotite schist contact specimens were particularly weak, both yielding ultimate uniaxial compressive strengths of less than 8,000 psi. These very low strengths were probably due to discontinuities present along the contact surface.

CHAPTER 4

SPECIAL TESTS

4.1 ANISOTROPY TESTS

Eight rock specimens from the Pembine Area were selected and prepared for determination of compressional and shear velocities according to the ASTM proposed method of test for laboratory determination of ultrasonic pulse velocities and elastic constants of rock. The NX-diameter specimens were cut to lengths of 2 inches and ground on the ends to a tolerance of 0.001 inch. Four 1/2-inch-wide strips were also ground down the sides of the cylindrical surface at 90-degree angles. The velocities, densities, and dimensions were measured as specified in the proposed test method. Results of velocity determinations are given in Table 4.1.

Compressional wave velocities exhibited by the several specimens tested were somewhat variable in magnitude, ranging from moderate to high. Significantly, however, variation within particular rock types was generally slight. The one exception was yielded by the two tonalites, one of which was highly fractured and exhibited somewhat lower velocities.

Deviations from the average compressional wave velocity were, in most instances, rather low. In all cases, deviations from the average were less than 6 percent--in most cases, less than 3 percent.

Expectedly, the fractured specimens yielded the greatest deviations from the average.

A compilation of the elastic properties computed from the compressive and shear velocities and the specific gravity is given in Table 4.2. However, particular discretion must be used in utilizing the moduli results, as experimental errors are introduced when the differences in velocities are significant. The proposed ASTM test method states that the equations for computation of elastic moduli should not be used if "any of the three compressional wave velocities varies by more than 2 percent from their average value. The error in Young's modulus (E) and shear modulus (G) due to both anisotropy and experimental error then does not exceed 6 percent." Naturally, the error is compounded by greater differences in the three-directional velocity measurements, as are present here.

The 2 percent allowable deviation proposed by the ASTM appears to be unrealistic since laboratory-determined values of compressional and shear wave velocities are reproducible within a deviation from the average of only 2 to 3 percent. Thus, it would appear that the point of division between isotropy and anisotropy would more realistically be in the range of 5 to 8 percent deviation from the average. It should be kept in mind, however, that this greater deviation would also allow a greater error in the computed values of E and G .

4.2 COMPARATIVE TENSILE TESTS

Seven NX-diameter rock specimens were selected in an attempt to represent the variation of rock type present in the core received from the drill holes in the Pembine Area. The specimens were prepared and tested for tensile strength according to the ASTM proposed "Standard Method of Test for Direct Tensile Strength of Rock Core Specimens." For comparative purposes, tensile splitting tests were conducted on specimens cut adjacent to the direct tensile test specimens. The test results are given in Table 4.3.

Direct tensile strengths exhibited by the material from this area were quite high, i.e., greater than 1,000 psi in all instances. In one case, a direct tensile stress of 3,220 psi was applied without rock failure; the strength of the rock exceeded the adhesive strength of the epoxy. This specimen could not be tested to failure, but 3,220 psi should represent the minimum direct tensile strength of this intact specimen.

Indirect (Brazilian) tensile strengths were often somewhat less than the corresponding magnitudes of direct strength. This rather unusual phenomenon was probably due to the vertically oriented fractures present in most specimens, which could easily have affected the indirect strengths without having any detrimental effect on direct strength (fractures perpendicular to plane of application of stress in this case).

In most cases, the direct tensile strength should better reflect the minimum tensile strength characteristic of a particular rock specimen since a specimen subjected to direct tension should be more prone to failure at a point of minimum strength, i.e., along fractures, etc. However, in cases in which fractures are oriented vertically, i.e., parallel to the axis of the core, indirect strengths may better reflect the minimum tensile strength of the rock, particularly if the fractures are not healed. Thus, tensile strength data must be viewed with due consideration given to nature and degree of fracturing present in the core.

4.3 PETROGRAPHIC EXAMINATION

4.3.1 Core Samples. Six boxes of NX-size core from holes in Dickinson County, Michigan, and Marinette and Oconto Counties, Wisconsin, were received for testing in November 1969. Each box contained about 15 feet of core representing several depths to 200 feet.

The cores were inspected to select representative pieces from all significant rock types for petrographic examination. The cores, as received, are described below.

(1) Hole PB-CR-2 (SAMSO-13, DC-1). The core was red and black, medium-grained tonalite with a small amount of black, fine-grained biotite schist.

Specimens 1 through 6, 8 through 14, and 19 through 26 were

tonalite, and Specimens 15 and 18 were contacts between the biotite schist and tonalite. Most of the specimens contained fractures that ranged from vertical to horizontal, but most of these fractures were healed and not open.

Specimens 7, 16, and 17 were biotite schist. Specimen 7 contained a 45-degree foliation, and Specimens 16 and 17 contained low-angle foliation and high-angle healed fractures.

(2) Hole PB-CR-20 (SAMSO-13, DC-2). The core was white and black, medium-grained granite and pink, medium-grained granite. The pink granite made up approximately two-thirds of the core, and the remainder of the core, Specimens 4, 5, 14, 16, 20, and 22, was gray granite. Specimens 2 and 17 contained contacts between pink granite and gray granite. Specimen 2, which was cut by a high-angle dike, contained the most fractures. Most of the remaining specimens appeared intact.

(3) Hole PB-CR-27 (SAMSO-13, DC-3). The core was dark gray, fine-grained amphibolite gneiss and blue, black, and brown, coarse-grained tonalite. Specimens 5, 6, 8 through 12, 20, and 21 were tonalite, and the remaining specimens were amphibolite. All of the specimens of tonalite contained fractures, as did most of the specimens of amphibolite. Specimens 15 and 16 contained contacts with a gray, fine-grained tonalite. In both specimens, the contacts were cut by shear fractures at 45 degrees.

(4) Hole PB-CR-40 (SAMSO-13, DC-4). The core was black, medium-grained biotite gneiss; gray and black, fine-grained quartz and amphibolite gneisses; and gray, medium-grained, tonalite gneiss. Specimens 1 through 3 were gray tonalite gneiss with a nearly horizontal foliation. Specimens 13, 14, and 17 were fine-grained quartz gneiss. Specimens 8, 18, and 22 were amphibolite gneiss. The remaining specimens were biotite gneiss. All of the specimens contained fractures, but none of the specimens appeared weathered.

Most of the specimens of biotite schist contained a well developed foliation. Specimens 5, 7, 11, 12, 20, and 21 were severely fractured, and Specimens 7, 11, 12, and 21 appeared altered.

All of the specimens of quartz gneiss contained fractures, but only Specimen 17 was severely fractured. These specimens did not appear weathered.

(5) Hole PB-CR-16 and -16A (SAMSO-13, DC-5). The entire core was dark green, medium-grained amphibolite gneiss that contained numerous fractures. The number and orientation of the fractures varied from specimen to specimen. Specimens 5A through 8A, 11A, and 14A contained critical-angle fractures sealed with calcite. Specimen 13A contained open, high-angle fractures. Specimens 1A and 2A were slightly weathered.

(6) Hole PB-CR-10 (SAMSO-13, DC-6). The core ranged from gray to pink, medium-grained tonalite. The gray tonalite was

coarser grained than the pink tonalite and contained fewer fractures. Specimens 1 through 5 were the gray tonalite, and Specimens 9 through 12 and 14 through 25 were the pink tonalite. Specimens 6 through 8 were transitional from gray to pink, and Specimen 13 was a dark green schistose inclusion in the pink tonalite. Specimens 6 through 8 were severely altered, and Specimens 9 through 12, 17, and 21 were severely fractured.

4.3.2 Specimens Selected for Examination. The specimens selected for petrographic examination were as follows:

Hole No.	CD Serial No.	Specimen No.	Approximate Depth	Rock Description
			feet	
PB-CR-2	SAMSO-13, DC-1	6	47	Red and black, medium-grained tonalite with a 1/2-inch-thick vertical quartz vein
		11	88	Black and red, medium-grained tonalite with several horizontal fractures
PB-CR-20	SAMSO-13, DC-2	8	77	White and black, medium-grained granite
		16	150	Pink, medium-grained granite

(Continued)

Hole No.	CD Serial No.	Specimen No.	Approximate Depth	Rock Description
			feet	
PB-CR-27	SAMSO-13, DC-3	10	104	Blue, black, and white, coarse-grained tonalite with nearly vertical and horizontal fractures
		16	164	Black, fine-grained amphibolite with an inclusion of fine-grained tonalite
PB-CR-40	SAMSO-13, DC-4	3	16	Black and white, medium-grained tonalite with several sealed fractures
		6	43	Black and gray, medium- to fine-grained biotite gneiss
		14	123	Black and gray, medium-grained quartz gneiss with fine-grained tonalite inclusions
PB-CR-16A	SAMSO-13, DC-5	17	176	Dark green, medium-grained amphibolite with three calcite-filled critical-angle fractures
PB-CR-10	SAMSO-13, DC-6	2	14	Gray, medium-grained tonalite with a healed low-angle fracture
		21	169	Pink, medium-grained tonalite with many high-angle fractures

4.3.3 Test Procedure. Each piece of core was sawed axially yielding two sections that were both designated by the original specimen number. One sawed surface of each piece was polished and photographed. Composite samples were obtained from the whole length or from selected portions from the half of each piece that was not polished and photographed. The composite samples were ground to pass a No. 325 sieve (44 μm). X-ray diffraction (XRD) patterns were made of each sample as a tight-packed powder. All XRD patterns were made using an XRD-5 diffractometer with nickel-filtered copper radiation. The samples X-rayed are listed as follows:

Hole No.	Serial No.	Specimen No.	Description of X-Ray Sample
PB-CR-2	SAMSO-13, DC-1	2	Entire length except for vertical quartz vein
		11	Entire length of core
PB-CR-20	SAMSO-13, DC-2	8	Entire length of core
		16	Entire length of core
PB-CR-27	SAMSO-13, DC-3	10	Entire length of core
		16	(a) Fine-grained amphibolite (b) Medium-grained tonalite
PB-CR-40	SAMSO-13, DC-4	3	Entire length of core

(Continued)

Hole No.	Serial No.	Specimen No.	Description of X-Ray Sample
PB-CR-40 (Cont'd)	SAMSO-13, DC-4	6	Entire length of core
		14	Entire length of core
PB-CR-16A	SAMSO-13, DC-5	17	Entire length of core
PB-CR-10	SAMSO-13, DC-6	2	Entire length of core
		21	Entire length of core

Small portions of the powdered samples were tested with dilute hydrochloric acid and with a magnet to determine whether carbonate minerals or magnetite were present.

The polished surface of each section was examined with a stereomicroscope. Thin sections were prepared from each section of core and examined with a polarizing microscope. A point-count modal analysis was made on each thin section in which a count was made at 500 points.

4.3.4 Results. The cores examined from the Pembine Area can be divided into three groups, according to bulk composition: granites (Reference 1), tonalites (Reference 1), and gneisses. All of the cores were taken from the Precambrian rocks near the Iron River-Crystal Falls and Menominee Districts of northern Michigan and northwestern Wisconsin (Reference 3). Core PB-CR-2 was taken from a

strongly deformed tonalite gneiss in the area of the Peavy Node, north of the Menominee District (Reference 4). This tonalite was the southernmost member of the southern complex of northern Michigan. Cores PB-CR-16 and -16A were taken from the metavolcanic rocks of the Quinnesec formation to the south of the Menominee District (Reference 5). Cores PB-CR-20 and -27 were taken from lower Precambrian Amberg granites, and Core PB-CR-10 was taken from the Newingham granodiorite west of the Menominee District. Core PB-CR-40 was taken from metavolcanic rocks in northwest Oconto County.

The cores examined included more tonalites than granites or gneisses. The rocks represented by these cores have undergone geologic histories similar to those of the rocks from the Michigamme Area to the north. The rocks in the Pembine Area had undergone a wide range of thermal and dynamic metamorphic effects. As in the Michigamme Area, metamorphic rank and degree of shearing were not directly related, as rocks of low metamorphic rank were often the most severely sheared. The rocks in each core are discussed below. The modal composition of each type is shown in Tables 4.4 through 4.6, and the bulk composition by XRD in Tables 4.7 through 4.9.

(1) Granites (Core PB-CR-20). These rocks ranged from gray, fine-grained to pink, medium-grained granite. Both rocks had undergone slight shearing and recrystallization, but the pink granite had

been more altered. The rocks had similar compositions and may represent textural variations within the same body. Differences in the compressive strengths of these rocks were minor except for those of Section 2, which was severely fractured.

(a) Section 8 of Core PB-CR-20 (SAMSO-13, DC-2). This section was typical of the pink granites in this core. The rock was medium-grained (Figure 4.1) and consisted of nearly equal amounts of microcline, plagioclase, and quartz and a small amount of biotite (Table 4.4). The section was slightly altered; plagioclase with an anorthite content of 15 percent was partially altered to sericite, and quartz was only slightly strained. Microcline and biotite were unaltered. There were a few microfractures present that had been filled with calcite.

(b) Section 16 of Core PB-CR-20 (SAMSO-13, DC-2). Though this section had a composition similar to that of Section 8 of Core PB-CR-20, it was much finer grained (Figure 4.1). The rock was gray, fine-grained granite. The modal composition was quite similar to that of Section 8. Plagioclase with an anorthite content of 21 percent and quartz and microcline in approximately equal amounts were the major constituents (Table 4.4). Biotite was slightly more abundant than in Section 8 of this core but was partially altered to chlorite. Plagioclase was slightly altered to sericite, but microcline and quartz were unaltered. This section contained no fractures.

(2) Tonalites (Core PB-CR-10 and Parts of Cores PB-CR-2 and -27). The tonalites were the most abundant rock type in the cores received for testing from this area. The rocks ranged from severely sheared to intact and from high metamorphic rank to unaltered. The tonalites fell into two distinct groups based on location and plagioclase content. Tonalites in Core PB-CR-2 (Table 4.5) were taken from the southernmost extension of the southern complex and contained less than 30 percent plagioclase. The remaining tonalites were taken from the younger igneous rocks south of the southern complex and contained an average of 50 percent plagioclase. Core PB-CR-2 comprised rocks that had undergone dynamic and thermal metamorphism. The effects upon the remaining cores were predominantly dynamic.

(a) Section 6 of Core PB-CR-2 (SAMSO-13, DC-1). This section was representative of 75 percent of this core. It was brick red and black, medium-grained tonalite, severely sheared and partially recrystallized. A large amount of secondary muscovite, chlorite, and pyrite had formed in the section. There were two healed fractures at the critical angle; along these fractures several large grains of pyrite had formed (Figure 4.2). Pyrite grains were also common along a 1/2-inch-thick vertical quartz vein that formed later than the fractures. Plagioclase was so severely altered to sericite that the anorthite content could not be determined. The reduction of grain

size by shearing was apparent in all the primary minerals. The modal composition is shown in Table 4.5, and the bulk composition in Table 4.8.

(b) Section 11 of Core PB-CR-2 (SAMSO-13, DC-2). This section contained less quartz and much more mica than did Section 6 (Table 4.5). Although the section contained many fractures, there was less grain size reduction than in Section 6. The section was cut by many horizontal fractures (Figure 4.2) along which secondary calcite and pyrite were common. The horizontal fractures represent the latest dynamic deformation to affect the section, as they cut and offset a set of high-angle fractures. Muscovite and chlorite were common secondary products in this rock.

(c) Section 2 of Core PB-CR-10 (SAMSO-13, DC-6). The section was gray, medium-grained tonalite. Plagioclase, with an anorthite content of 28 percent, made up over 50 percent of the rock (Table 4.5). The plagioclase was partially altered to sericite, and the biotite to chlorite. Low-angle healed fractures cut this section (Figure 4.3); subsequent alteration along the fractures had changed the color to pink. Bulk composition is shown in Table 4.8.

(d) Section 21 of Core PB-CR-10 (SAMSO-13, DC-6). The section was pink, medium-grained tonalite with a well developed high-angle planar structure (Figure 4.3) apparently produced by shearing, granulation and extension of the plagioclase, and orientation of the

long axes of the quartz in the same direction. All of the primary minerals were crushed and altered to varying degrees. The planar shear structure was subsequently disrupted by formation of two sets of high-angle fractures (Figure 4.3). These fractures were sealed with hematite and calcite. The section probably represents the sheared equivalent of Section 2 of Core PB-CR-10; the compositions of the two were very similar (Tables 4.5 and 4.8).

(e) Section 10 of Core PB-CR-27 (SAMSO-13, DC-3). The section was blue, brown, and black, coarse-grained tonalite. All of the primary minerals had been altered slightly. Plagioclase and microcline were altered to sericite, and biotite and hornblende to chlorite. The section was cut by several sealed low- and high-angle fractures, which appeared to be unrelated to the mineralogical alteration (Figure 4.4). The section contained an inconspicuous low-angle flow structure.

(f) General. Within the tonalite specimens tested, differences in compressive strength and elastic properties appear to have been influenced by differences in degree of fracturing, orientation of fractures, and extent of recrystallization of the rock following shearing. Variations in mineral composition among the specimens did not appear to affect the properties tested. Modal and bulk compositions of the tonalite cores are shown in Tables 4.5 and 4.8, respectively.

(3) <u>Gneisses (Cores PB-CR-40, -16A, and Parts of Cores PB-CR-2 and -27)</u>. This group showed the widest range in composition and structure of all the rocks examined from the Pembine Area. Most of these were amphibolites; the others ranged from tonalite gneiss to predominantly quartz gneiss. Many specimens were sheared or fractured and exhibited a wide range in grain size. The rocks ranged from those that were foliated to those without apparent structure.

(a) <u>Section 3 of Core PB-CR-40 (SAMSO-13, DC-4)</u>. The section was a gray, medium-grained tonalite containing sheared and disrupted augen of quartz and feldspar (Figure 4.5). The few large grains present exhibited granulated borders, and most of the primary minerals had been crushed and recrystallized. Plagioclase was almost completely altered to sericite, which prevented determination of the anorthite content, but biotite and hornblende were only partially altered to chlorite. Modal and bulk compositions are shown in Tables 4.6 and 4.9, respectively.

(b) <u>Section 6 of Core PB-CR-40 (SAMSO-13, DC-4)</u>. This section was fine- to medium-grained, black and gray, biotite-hornblende gneiss, with foliation dipping at 40 to 50 degrees (Figure 4.5). Hornblende and quartz were common in the medium-grained areas, and plagioclase and biotite were common in the fine-grained areas. None of the minerals appeared to be altered, possibly because they were

recrystallized. Modal and bulk compositions are shown in Tables 4.6 and 4.9, respectively.

(c) Section 14 of Core PB-CR-40 (SAMSO-13, DC-4). The section consisted of about 60 percent quartz, 25 percent plagioclase, and 10 percent hornblende (Table 4.6). It ranged from medium- to fine-grained and had been severely sheared, in part recrystallized, and subjected to several episodes of fracturing. The quartz was granulated and recrystallized, and the plagioclase was completely altered to sericite. Bulk composition is shown in Table 4.9.

(d) Section 17 of Core PB-CR-16A (SAMSO-13, DC-5). The section was dark green, medium-grained amphibolite showing a foliation or preferred orientation dipping steeply. The section is traversed by gash fractures at about 45 degrees filled with calcite (Figure 4.6). Hornblende has been severely altered to chlorite, and plagioclase completely altered to sericite. Quartz occurred as small scattered interstitial grains. Modal and bulk compositions are shown in Tables 4.6 and 4.9, respectively.

(e) Section 17 of Core PB-CR-2 (SAMSO-13, DC-1). The section was black, fine-grained, biotite gneiss that had been sheared and severely altered. Biotite was partially altered to chlorite, and epidote was a conspicuous metamorphic product. There was a large amount of calcite present as vein fillings. The section was cut by steeply dipping fractures, low-angle fractures, and two almost

vertical fractures (Figure 4.7). Modal and bulk compositions are shown in Tables 4.6 and 4.9, respectively.

(f) Section 16 of Core PB-CR-27 (SAMSO-13, DC-3). The section was black, fine-grained, hornblende-biotite gneiss with an inclusion of gray, medium-grained tonalite. The section was cut by several low- and high-angle fractures that were usually sealed with calcite. The gneiss was not severely altered, as plagioclase was partially altered to sericite and biotite was slightly altered to chlorite (Figure 4.7). The tonalite had been crushed and recrystallized. Modal and bulk compositions are shown in Tables 4.6 and 4.9. respectively.

4.3.5 Summary. Thirteen specimens of NX-size core from six drill holes in the Pembine Area of northwest Wisconsin and northern Michigan were examined. The four major rock types were granites, tonalites, amphibolite gneisses, and biotite gneisses. The tonalites were the most abundant rock types. The rocks were all essentially unweathered.

TABLE 4.1 VELOCITY DETERMINATIONS

	Velocity: Compressional[a]	Velocity: Shear[a]
	ft/sec	ft/sec
Hole PB-CR-2, Specimen 21:		
Tonalite, highly fractured	16,020	8,500
Depth: 144 feet	15,310	8,360
Specific gravity: 2.65	16,260	8,650
Compressional deviation:[b] 3.5 pct		
Average	15,860	8,500
Hole PB-CR-10, Specimen 4:		
Tonalite, intact	19,500	9,570
Depth: 38 feet	19,890	9,710
Specific gravity: 2.70	19,890	9,760
Compressional deviation:[b] 1.3 pct		
Average	19,760	9,680
Hole PB-CR-16A, Specimen 4A:		
Amphibolite gneiss, fractured	22,730	10,590
Depth: 48 feet	20,910	10,190
Specific gravity: 2.96	20,770	10,120
Compressional deviation:[b] 5.9 pct		
Average	21,470	10,300
Hole PB-CR-16A, Specimen 14A:		
Amphibolite gneiss, fractured	21,630	9,800
Depth: 148 feet	22,380	10,430
Specific gravity: 2.83	21,750	10,400
Compressional deviation:[b] 2.2 pct		
Average	21,990	10,210
Hole PB-CR-20, Specimen 11:		
Granite	17,080	8,310
Depth: 108 feet	16,670	8,780
Specific gravity: 2.65	16,620	8,490
Compressional deviation:[b] 1.7 pct		
Average	16,790	8,530
Hole PB-CR-20, Specimen 22:		
Granite	16,380	8,700
Depth: 183 feet	16,850	8,840
Specific gravity: 2.68	17,250	8,810
Compressional deviation:[b] 2.7 pct		
Average	16,830	8,780
Hole PB-CR-27, Specimen 14:		
Amphibolite gneiss	20,770	9,990
Depth: 145 feet	21,220	10,340
Specific gravity: 2.90	21,280	10,440
Compressional deviation:[b] 1.5 pct		
Average	21,090	10,260

[a] First velocity listed is in axial (longitudinal) direction; other two are on mutually perpendicular, diametral (lateral) axes.
[b] Maximum percent deviation from the average of the compressional wave velocity.

TABLE 4.2 DYNAMIC ELASTIC PROPERTIES

Hole No.	Specimen No.		Modulus			Poisson's Ratio
			Young's	Shear	Bulk	
			10^6 psi	10^6 psi	10^6 psi	
PB-CR-2	21		6.7	2.6	5.7	0.30
			6.4	2.5	5.0	0.29
			7.0	2.7	5.9	0.30
		Average	6.7	2.6	5.5	0.30
PB-CR-10	4		8.9	3.3	9.4	0.34
			9.2	3.4	9.8	0.34
			9.3	3.5	9.8	0.34
		Average	9.1	3.4	9.7	0.34
PB-CR-16A	4A		12.1	4.5	14.6	0.36
			11.1	4.2	11.9	0.34
			10.9	4.1	11.7	0.34
		Average	11.4	4.3	12.7	0.35
PB-CR-16A	14A		10.0	3.7	13.3	0.37
			11.3	4.2	13.6	0.36
			11.1	4.1	12.6	0.35
		Average	10.8	4.0	13.2	0.36
PB-CR-20	11		6.6	2.5	7.1	0.34
			7.2	2.8	6.2	0.31
			6.8	2.6	6.4	0.32
		Average	6.9	2.6	6.6	0.32
PB-CR-20	22		7.1	2.7	6.0	0.30
			7.4	2.8	6.5	0.31
			7.4	2.8	7.0	0.32
		Average	7.3	2.8	6.5	0.31
PB-CR-27	14		10.5	3.9	11.6	0.35
			11.2	4.2	12.0	0.34
			11.4	4.2	12.0	0.34
		Average	11.0	4.1	11.9	0.34

TABLE 4.3 TENSILE STRENGTH DETERMINATIONS

Hole No.	Specimen No.	Depth	Tensile Strength		Core Description
			Splitting	Direct	
		feet	psi	psi	
PB-CR-2	21	144	2,140	1,380	Tonalite, highly fractured
PB-CR-10	4	38	900	1,600	Tonalite, intact
PB-CR-16A	4A	48	1,320	2,770	Amphibolite gneiss, fractured vertically
PB-CR-16A	14A	148	1,380	1,250	Amphibolite gneiss, fractured vertically
PB-CR-20	11	108	730	1,020	Granite, intact
PB-CR-20	22	183	1,320	1,610	Granite, intact
PB-CR-27	14	145	1,230	3,220[a]	Amphibolite gneiss, intact

[a] Rock strength exceeded adhesive strength of epoxy; failure occurred in epoxy. Therefore, the value presented should be a minimum value of direct tensile strength.

TABLE 4.4 MODAL COMPOSITION OF GRANITES FROM THE PEMBINE AREA

Composition is based on count at 500 points in each thin section.

Constituent	Percent of Constituent in Core PB-CR-20 (SAMSO-13, DC-2)	
	Section 8	Section 16
Quartz	29	29
Plagioclase	30	30
Microcline	34	28
Biotite	6	10
Magnetite	Trace	Trace
Zircon	Trace	Trace
Chlorite	--	2
Epidote	--	Trace
Calcite	Trace	Trace

TABLE 4.5 MODAL COMPOSITION OF TONALITES FROM THE PEMBINE AREA

Composition is based on count at 500 points in each thin section.

Constituent	Percent of Constituent in Indicated Cores				
	Core PB-CR-2 (SAMSO-13, DC-1 and -2)		Core PB-CR-10 (SAMSO-13, DC-6)		Core PB-CR-27 (SAMSO-13, DC-3) Section 10
	Section 6	Section 11	Section 2	Section 21	
Quartz	43	31	29	25	28
Plagioclase	28	26	52	56	42
Microcline	9	3	3	--	11
Biotite	3	15	12	4	9
Chlorite	1	10	2	8	4
Muscovite	10	6	Trace	1	--
Hornblende	--	--	--	--	3
Calcite	4	4	Trace	2	1
Magnetite	--	--	--	Trace	--
Pyrite	2	4	--	--	1
Hematite	--	--	--	1	--
Zircon	Trace	Trace	--	Trace	Trace
Apatite	Trace	Trace	Trace	Trace	Trace
Epidote	--	--	1	3	Trace

TABLE 4.6 MODAL COMPOSITION OF GNEISSES FROM THE PEMBINE AREA

Composition is based on count at 500 points in each thin section.

Constituent	Percent of Constituent in Indicated Cores						
	Core PB-CR-40 (SAMSO-13, DC-4)			Core PB-CR-16A (SAMSO-13, DC-5) Section 17	Core PB-CR-2 (SAMSO-13, DC-1) Section 17	Core PB-CR-27 (SAMSO-13, DC-3)	
	Section 3	Section 6	Section 14			Section 16a[a]	Section 16b[a]
Quartz	44	20	62	7	15	23	37
Plagioclase	31	21	26	9	7	21	48
Hornblende	8	15	9	42	--	28	--
Biotite	12	36	--	--	43	26	8
Chlorite	3	3	--	31	18	2	4
Microcline	--	--	--	--	--	--	3
Magnetite	2	4	2	--	--	Trace	--
Pyrite	--	--	--	--	3	--	--
Epidote	--	Trace	1	--	3	--	--
Zircon	--	Trace	--	--	Trace	Trace	Trace
Apatite	--	Trace	--	--	Trace	Trace	--
Calcite	Trace	--	--	11	10	--	Trace
Muscovite	--	--	--	--	Trace	--	--

[a] Section 16a is hornblende-biotite gneiss, and Section 16b is tonalite.

TABLE 4.7 BULK COMPOSITION OF GRANITES FROM THE PEMBINE AREA

Composition is based on XRD results.

Constituent	Amount of Constituent in Core PB-CR-20 (SAMSO-13, DC-2)	
	Section 8	Section 16
Quartz	Abundant	Abundant
Plagioclase	Abundant	Abundant
Microcline	Abundant	Abundant
Biotite	Minor	Minor
Chlorite	--	Trace

TABLE 4.8 BULK COMPOSITION OF TONALITES FROM THE PEMBINE AREA

Composition is based on XRD results.

Constituent	Amount of Constituent in Indicated Core				
	Core PB-CR-2 (SAMSO-13, DC-1 and -2)		Core PB-CR-10 (SAMSO-13, DC-6)		Core PB-CR-27 (SAMSO-13, DC-3) Section 10
	Section 6	Section 11	Section 2	Section 21	
Quartz	Abundant	Abundant	Abundant	Abundant	Abundant
Plagioclase	Abundant	Abundant	Abundant	Abundant	Abundant
Microcline	Minor	Trace	Trace	--	Minor
Biotite	Minor	Minor	Minor	Trace	Minor
Chlorite	--	Minor	Minor	Minor	--
Muscovite	Minor	Minor	--	--	--
Calcite	Trace	--	Trace	Trace	--
Pyrite	Trace	Trace	--	--	Trace
Hornblende	--	--	--	--	Minor

TABLE 4.9 BULK COMPOSITION OF GNEISSES FROM THE PEMBINE AREA

Composition is based on XRD results.

Constituent	Amount of Constituent in Indicated Cores						
	Core PB-CR-40 (SAMSO-13, DC-4)			Core PB-CR-16A (SAMSO-13, DC-5) Section 17	Core PB-CR-2 (SAMSO-13, DC-1) Section 17	Core PB-CR-27 (SAMSO-13, DC-3)	
	Section 3	Section 6	Section 14			Section 16a	Section 16b
Quartz	Abundant	Abundant	Abundant	Minor	Abundant	Abundant	Abundant
Hornblende	Minor	Minor	Minor	Abundant	--	Abundant	--
Biotite	Minor	Abundant	--	--	Abundant	Abundant	Minor
Chlorite	Trace	--	--	Abundant	Abundant	Trace	Trace
Plagioclase	Abundant	Abundant	Abundant	Minor	Minor	Abundant	Abundant
Magnetite	Trace	Trace	Trace	--	--	--	--
Epidote	--	--	Trace	--	--	--	--
Calcite	Trace	--	--	Minor	Minor	--	--
Pyrite	--	--	--	--	Trace	--	--

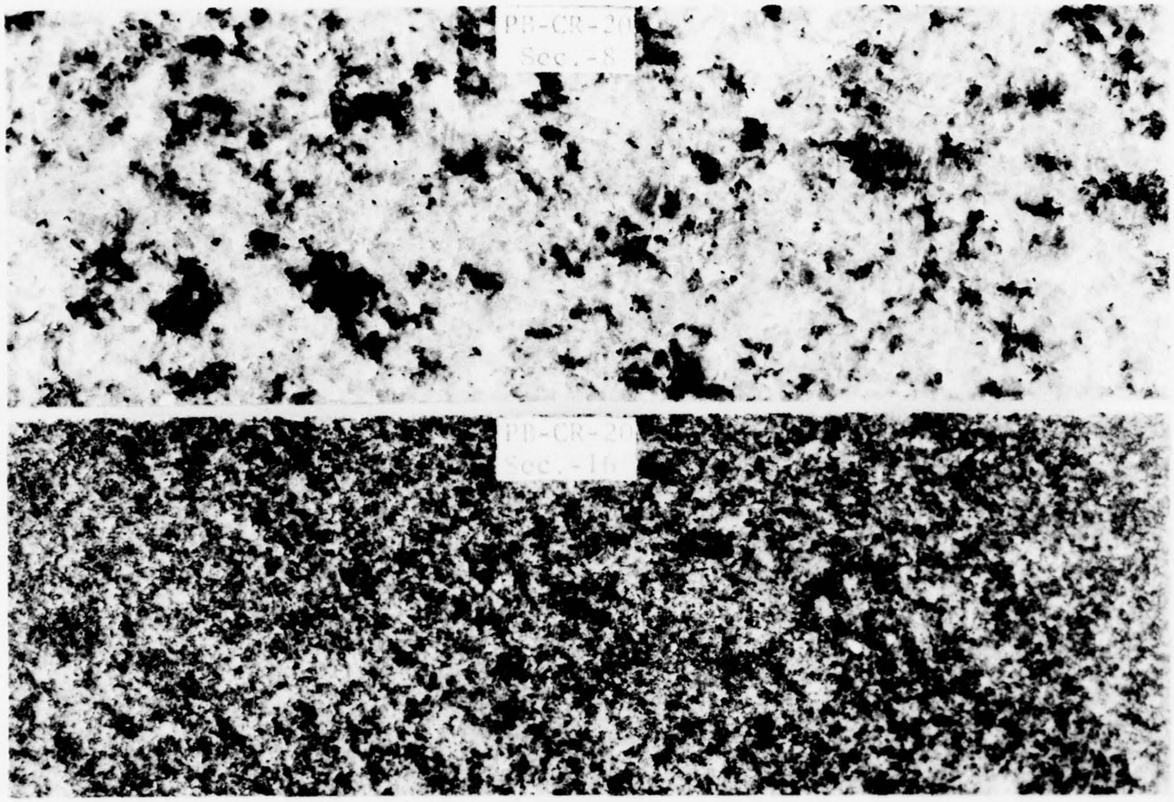


Figure 4.1 Sections 8 and 16 of Core PB-CR-20 (SAMSO-13, DC-2). In Section 8, no preferred orientation can be seen. The black grains are biotite. Section 16 shows a finer grained texture and darker color than Section 8, but no preferred orientation is shown.

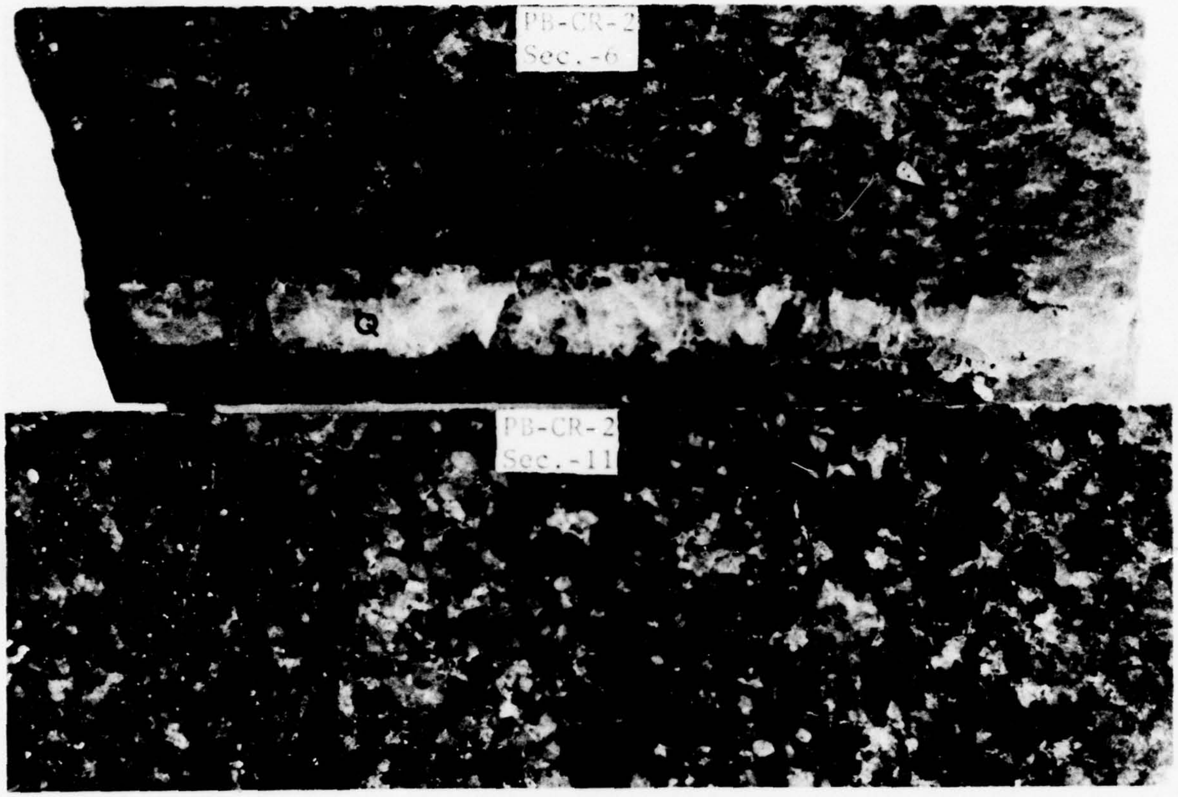


Figure 4.2 Sections 6 and 11 of Core PB-CR-2 (SAMSO-13, DC-1 and -2). Section 6 shows a change in texture at the right and left produced by recrystallization. Pyrite (P) is common along shear fractures and along the vertical quartz vein (Q). Section 11 is coarser grained than Section 6. Several flat-lying fractures and one curving shear fracture cut the section.

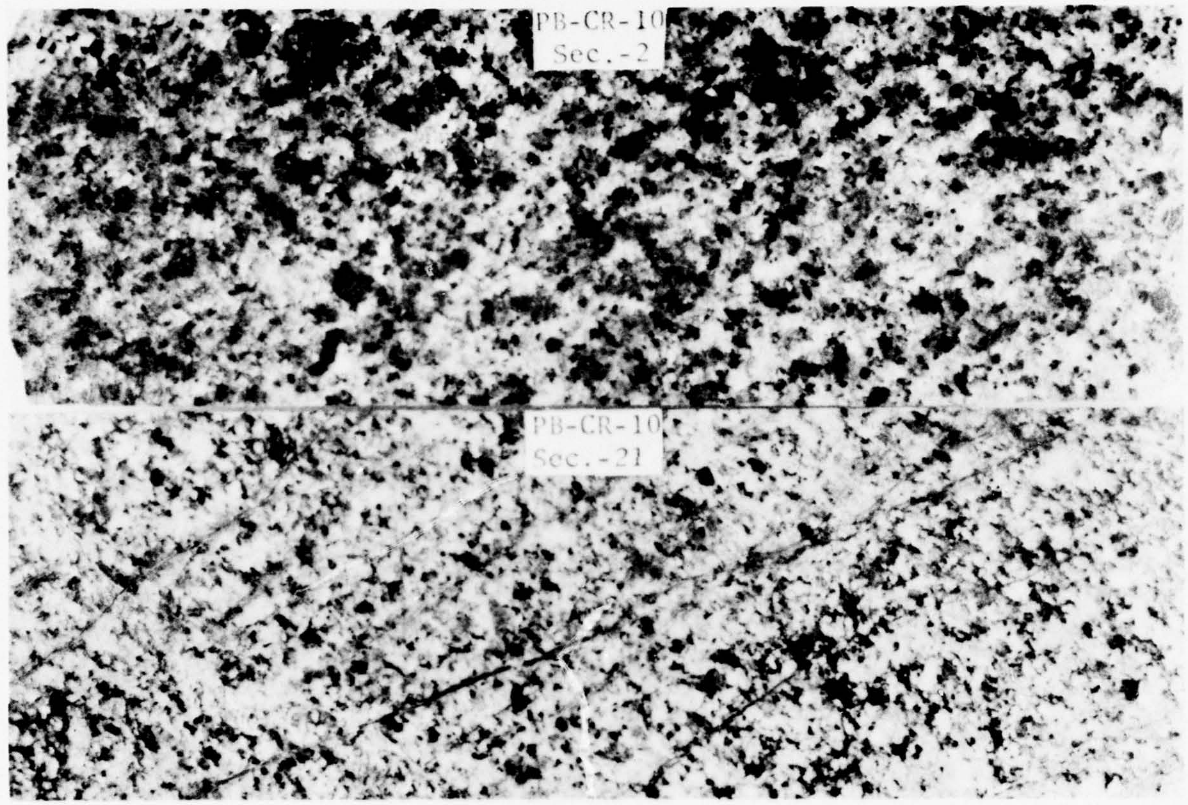


Figure 4.3 Sections 2 and 21 of Core PB-CR-10 (SAMSO-13, DC-6). Section 2 shows equigranular medium-grained texture of this tonalite. A low-angle shear fracture is marked by a line of white grains to the left of the label. Section 21 shows a high-angle planar structure that appears to be the result of shearing, transgressed by two sets of high-angle fractures.

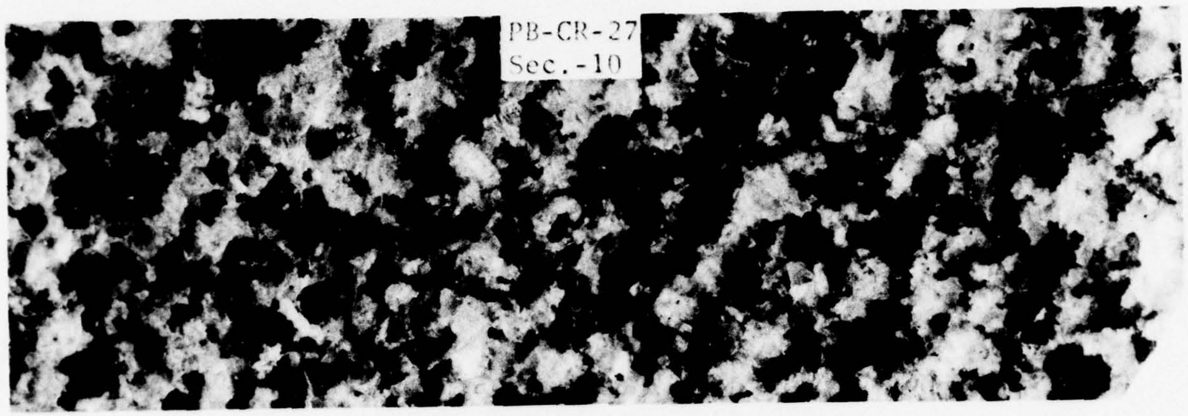


Figure 4.4 Section 10 of Core PB-CR-27 (SAMSO-13, DC-3). Note the coarse-grained equigranular texture of this tonalite. One steep fracture can be seen below and to the right of the label.

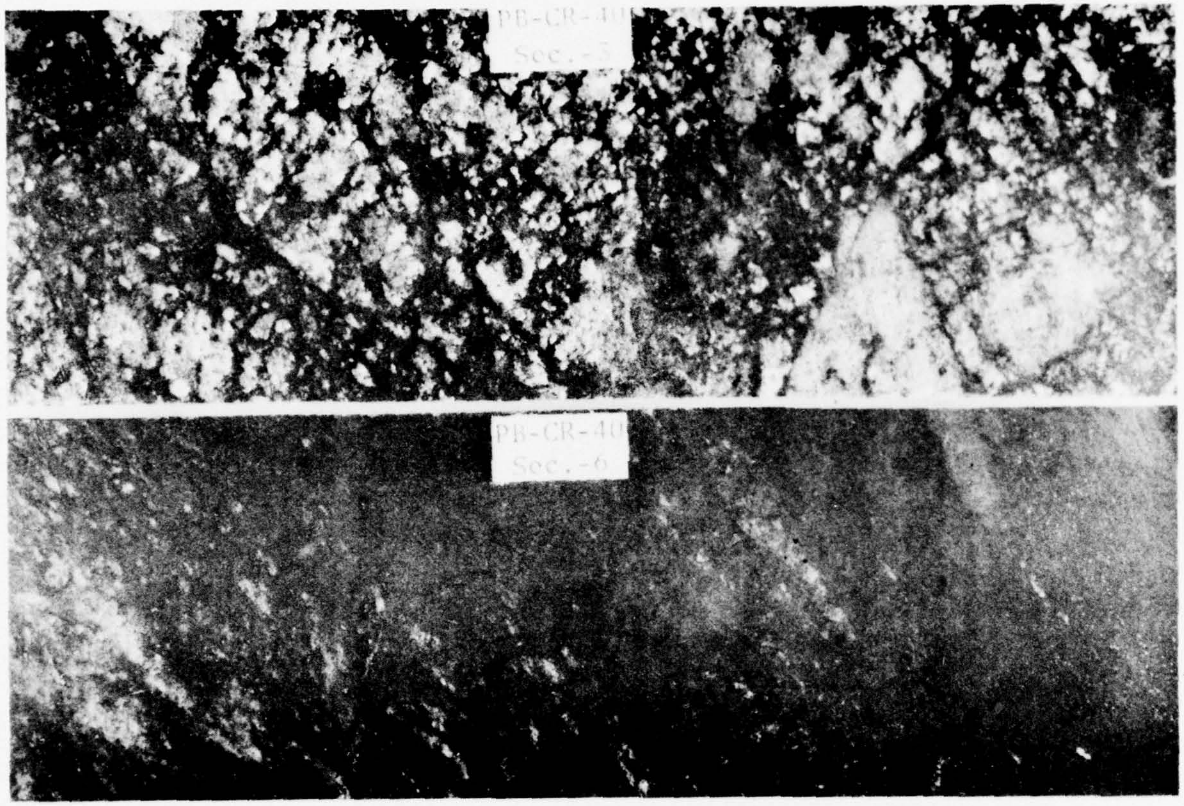


Figure 4.5 Sections 3 and 6 of Core PB-CR-40 (SAMSO-13, DC-4). Section 3 shows an augen structure that was later sheared. Section 6 shows a range in texture from fine-grained (right) to medium-grained (left) and well developed foliation dipping at about 40 to 50 degrees.

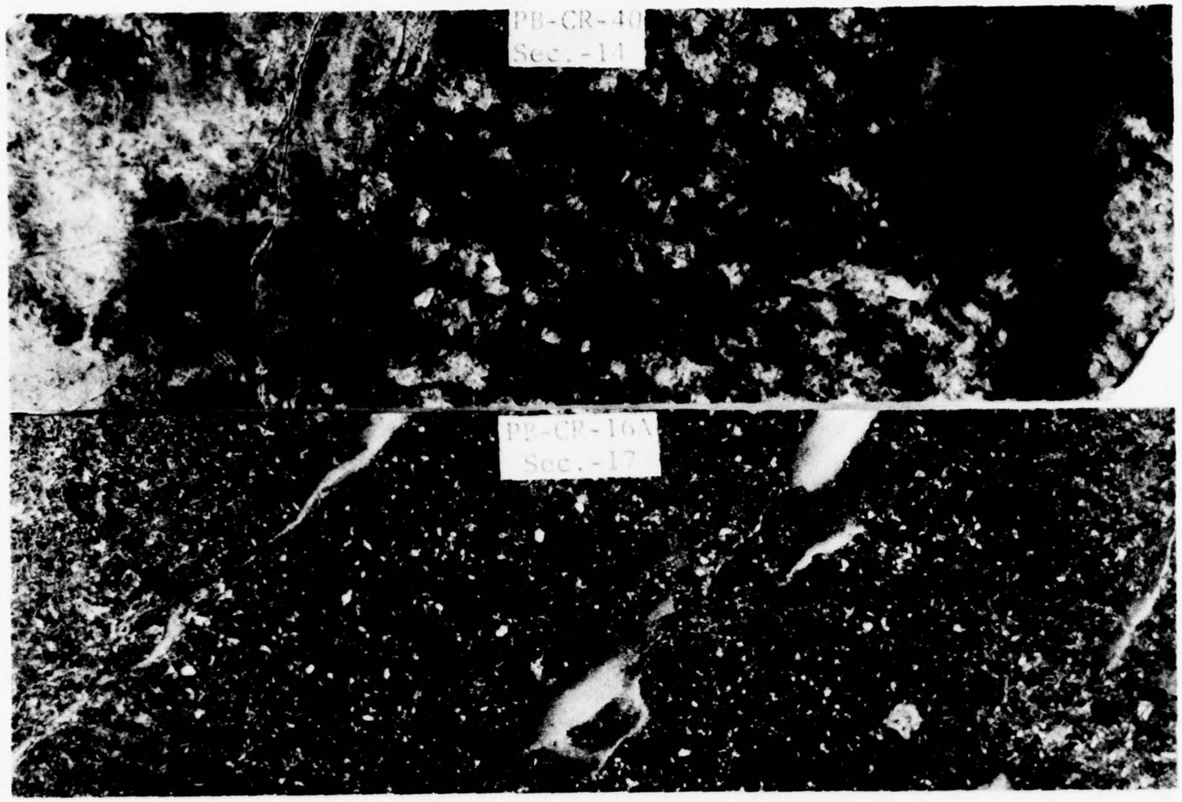


Figure 4.6 Section 14 of Core PB-CR-40 (SAMSO-13, DC-4) and Section 17 of Core PB-CR-16A (SAMSO-13, DC-5). The middle of Section 14 contains one set of fractures dipping at about 60 degrees, displaced by a later set dipping at 30 to 40 degrees. The left part of the photograph shows recrystallized fine-grained rock crisscrossed by nearly vertical and low-angle fractures. Section 17 shows an almost vertical structure cut by gash fractures at 45 degrees. The fractures have been sealed with calcite.

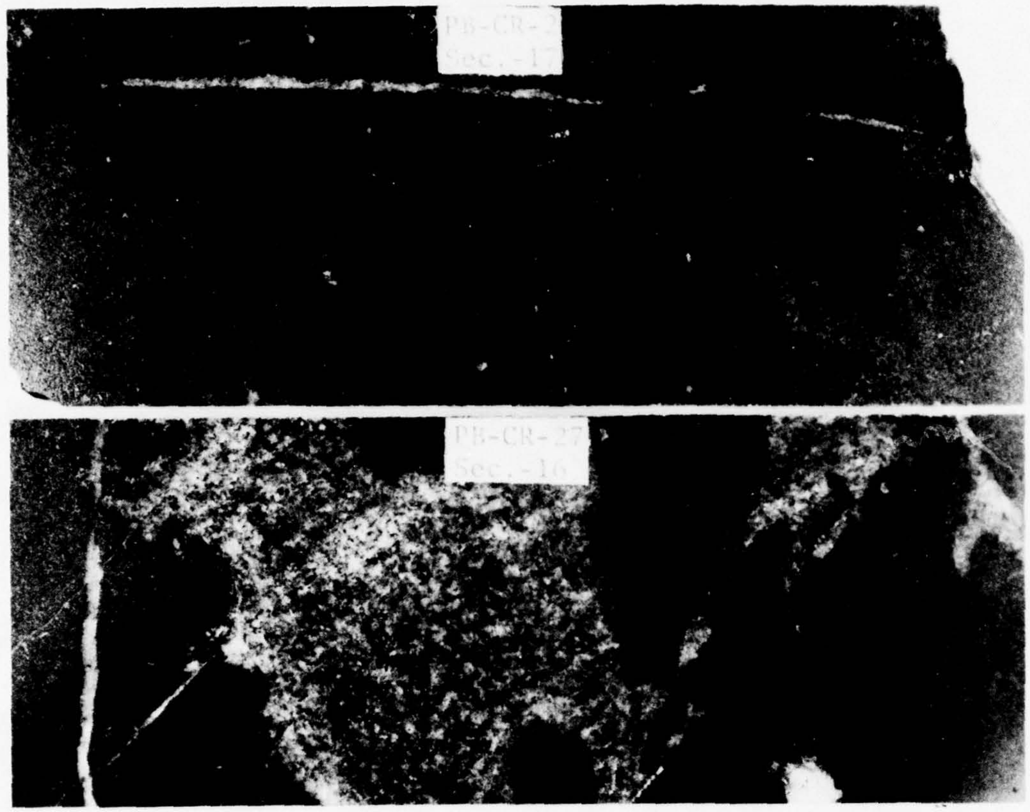


Figure 4.7 Section 17 of Core PB-CR-2 (SAMSO-13, DC-1) and Section 16 of Core PB-CR-27 (SAMSO-13, DC-3). Section 17 shows a very fine-grained texture and lack of foliation. To the right is a set of low-angle fractures, and below the label is a calcite-filled parting. Section 16 shows a gray tonalite gneiss inclusion in a fine-grained amphibolite. Both rocks were cut by several sets of fractures later sealed with calcite.

CHAPTER 5

DISCUSSION AND CONCLUSIONS

5.1 DISCUSSION

The nature of the objective of the rock quality tests reported herein dictates overall evaluation of the cores on a hole-to-hole basis. In the instances in which individual holes yielded core of only one rock type, the evaluation of the hole will, of course, be dictated by the characteristics of the particular rock type present. However, in those instances in which several rock types are represented in a single hole, the evaluation of the hole will necessarily reflect the quality of the least competent material tested.

To facilitate evaluation of the Pembine Area in this manner, a rock quality chart (Figure 5.1) was prepared. Ultimate uniaxial compressive strengths depicted on this chart were expressed in one of the three following categories: good (>12,000 psi), marginal (8,000 to 12,000 psi), and poor (<8,000 psi).

Locations of the individual drill holes are shown in Figure 5.2.

5.2 CONCLUSIONS

On the basis of physical test results exhibited by the specimens of rock core received from the Pembine Area, the following conclusions appear warranted:

1. The rock core received from the Pembine Area was identified

petrographically as predominantly tonalite, granite, amphibolite gneiss, and biotite gneiss, with relatively insignificant quantities of quartz gneiss and biotite schist.

2. Many specimens contained fractures that ranged in orientation from horizontal to vertical. The fractures in the core removed from Holes PB-CR-16 and -16A were sealed with calcite.

3. Physical test results exhibited by the rock core specimens from this study area ranged considerably in magnitude. The majority of the core yielded ultimate uniaxial compressive strengths typical of competent material (>12,000 psi). Several of the critically to highly fractured specimens and specimens containing calcite-sealed fractures exhibited physical test results that are characteristic of incompetent material.

4. The tonalite was generally marginal to competent in quality, the vast majority of the core exhibiting ultimate uniaxial compressive strengths greater than 12,000 psi. Three highly fractured specimens, however, were incompetent. All three were removed from Hole PB-CR-10.

5. The amphibolite gneiss ranged from incompetent to competent in quality, the majority of the lower quality rock coming from Cores PB-CR-16 and -16A. The fractures in the core from these holes were sealed with calcite, probably resulting in the somewhat lower strengths. Compressional wave velocities were relatively unaffected by the calcite.

6. The granite tested from Hole PB-CR-20 was very competent material, with the ultimate uniaxial compressive strength averaging approximately 33,000 psi. Fractures appeared to have little or no effect on ultimate strengths and compressional wave velocities. Compressional wave velocities were quite uniform, but unusually low for a material exhibiting such high ultimate uniaxial compressive strengths.

7. The biotite gneiss removed from Hole PB-CR-40 was somewhat variable, but very competent; ultimate uniaxial compressive strengths ranged from approximately 25,000 to 55,000 psi.

8. The quartz gneiss removed from Hole PB-CR-40 was relatively competent rock, exhibiting physical test results in the same general range as those exhibited by the biotite gneiss also removed from that hole.

9. The two tonalite-biotite schist contact specimens received from Hole PB-CR-2 were very incompetent, both yielding ultimate uniaxial compressive strengths less than 8,000 psi. This incompetence was probably due to discontinuities present along the contact surfaces.

10. Elastic constants determined for the material from this area ranged from moderate to high in magnitude. The granite, one of the more competent materials tested, yielded the lower values, along with the tonalite. The fractured amphibolite gneiss yielded the highest

values. Generally, static moduli were slightly higher than their corresponding dynamic values.

11. All of the material from this area was somewhat inelastic. Most was quite brittle, exhibiting little plastic deformation prior to catastrophic failure. Cyclic stress-strain curves usually depicted slight hysteresis, with strain completely recoverable upon unloading.

12. Anisotropy tests revealed that the material from this area was slightly anisotropic, deviations from the average compressional wave velocity generally being less than 3 percent and in no case greater than 6 percent.

13. Tensile strengths exhibited by the various rock types were very high; direct strengths were, in all cases, greater than 1,000 psi.

14. Evaluation of the Pembine Area core on a hole-to-hole basis indicates that the granite removed from Hole PB-CR-20 and the biotite and quartz gneiss removed from Hole PB-CR-40 are quite competent materials that should offer good possibilities as competent hard rock media.

The tonalite and amphibolite gneiss removed from Hole PB-CR-27 were found to be relatively competent rock, with only one specimen, an amphibolite gneiss, yielding physical test results characteristic of marginal quality rock. Generally, this hole yielded material that should offer some possibility as a competent hard rock medium.

Holes PB-CR-2, -10, and -16A generally yielded rock core that

exhibited rather varied physical properties. Though much of the rock was relatively competent in quality, several specimens from each hole, which were removed from depths greater than 50 feet below ground surface, were found to be quite incompetent. The scattered presence of these poor quality materials at depths of greater than 50 feet is sufficient to justify classification of the core from these three holes as unsuitable, incompetent media.

The evaluations and conclusions above were based on somewhat limited data. Therefore, more extensive investigation will be required in order to fully define the individual areas under consideration.

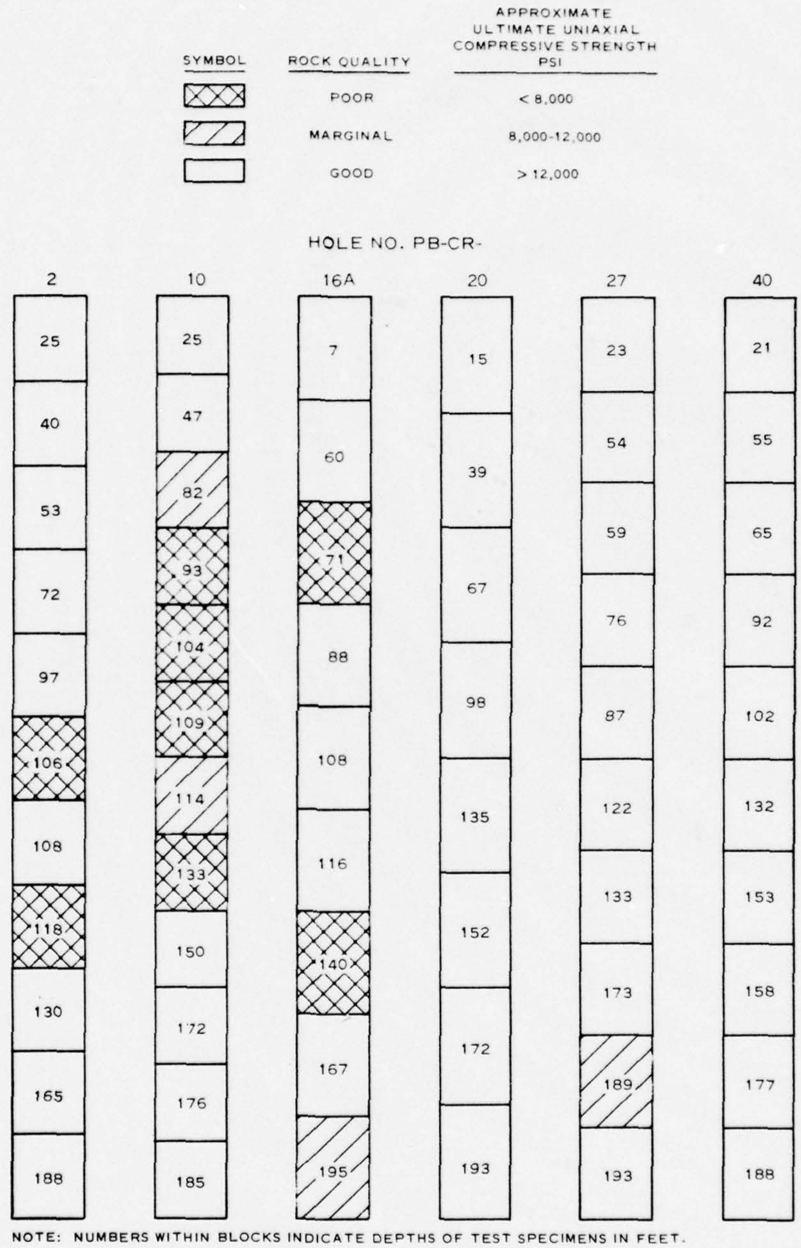
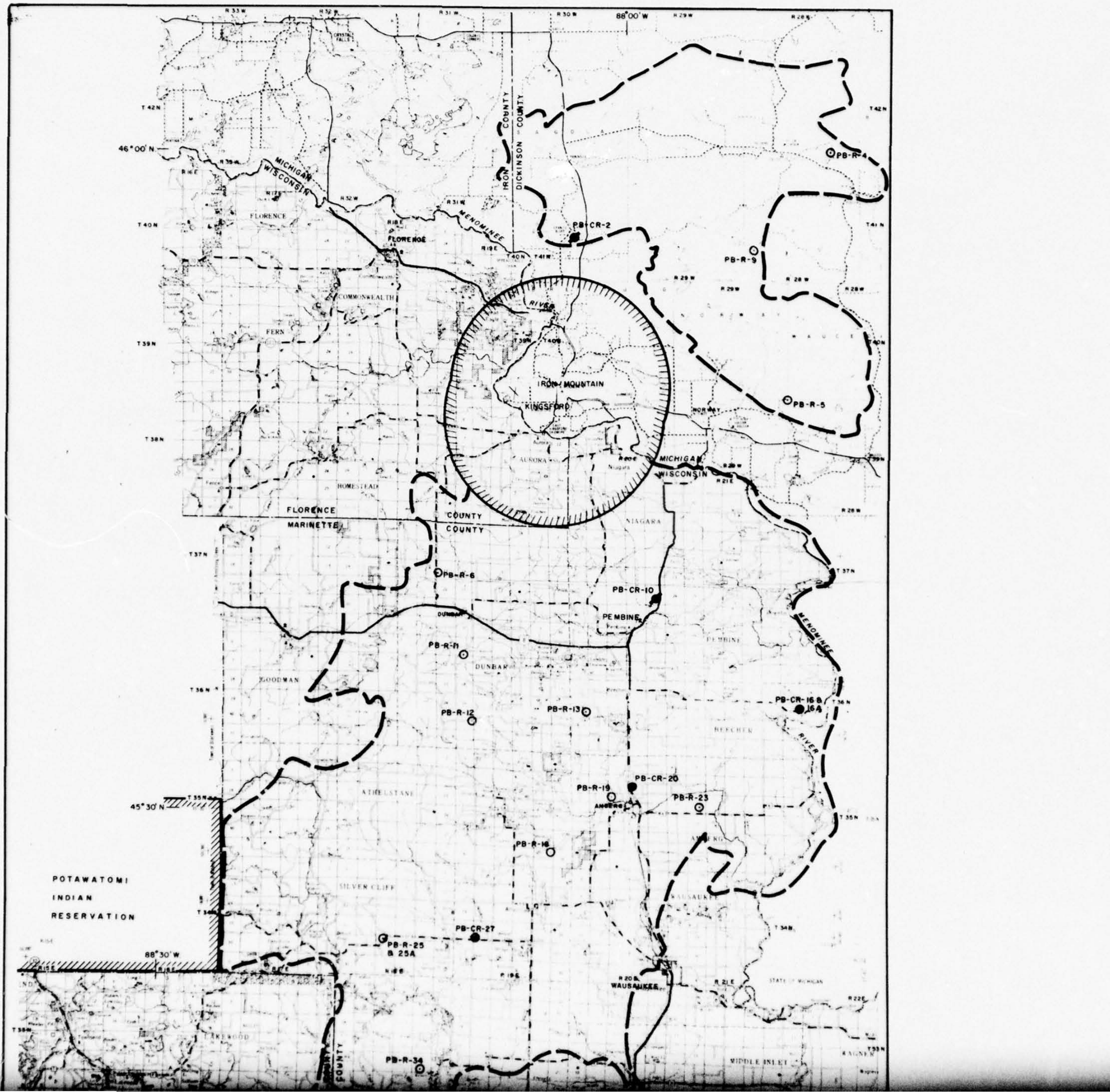


Figure 5.1 Depth versus quality as indicated by compressive strength for individual holes.



88°00'W
46°00'N
45°30'N
88°30'W
MICHIGAN
WISCONSIN
IRON COUNTY
DICKINSON COUNTY
FLORENCE
MARINETTE
COUNTY
COUNTY
MENOMINEE
RIVER
IRON MOUNTAIN
KINGSFORD
FLORENCE
COMMONWEALTH
FERN
HOMESTEAD
AURORA
NIAGARA
PEMBINE
DUNBAR
GOODMAN
BEECHER
ATHELSTANE
SILVER CLIFF
WAUSAUKEE
MIDDLE INLET
LAKEWOOD
POTAWATOMI
INDIAN
RESERVATION
PB-R-4
PB-R-5
PB-R-9
PB-CR-2
PB-R-6
PB-CR-10
PB-R-11
PB-R-12
PB-R-13
PB-CR-16 & 16A
PB-R-19
PB-CR-20
PB-R-23
PB-R-18
PB-CR-27
PB-R-25 & 25A
PB-R-34
T42N
T41N
T40N
T39N
T38N
T37N
T36N
T35N
T34N
T33N
R33W
R32W
R31W
R30W
R29W
R28W
R18E
R19E
R20E
R21E
R22E

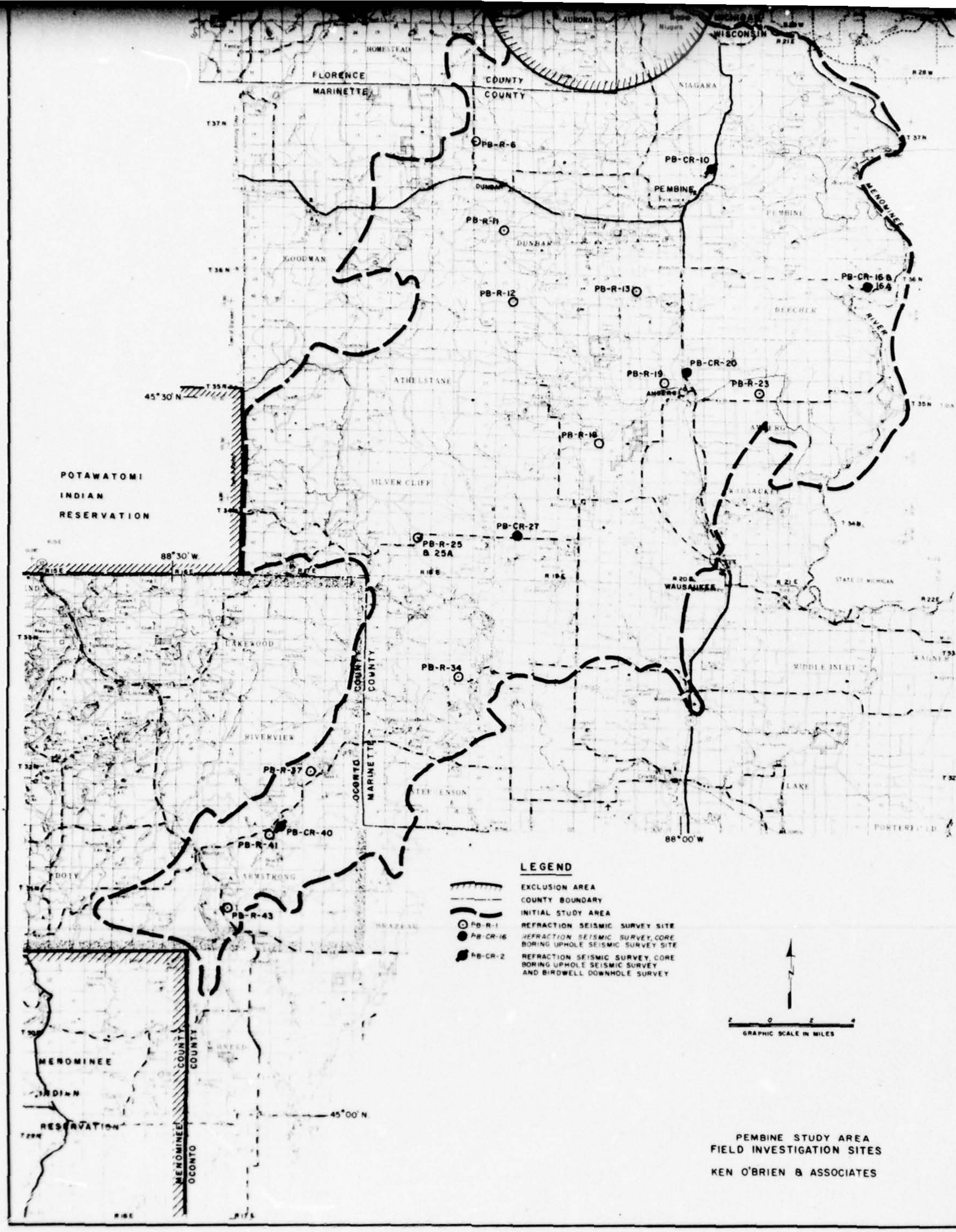


Figure 5.2 Field investigation sites.

APPENDIX A

DATA REPORT

Hole PB-CR-2

25 November 1969

Hole Location: Dickinson County, Michigan

Township 41N, Range 30W, Section 22

Longitude: 45° 56' North

Latitude: 88° 03' West

Core

1. The following core was received on 7 November 1969 for testing:

Core Piece No.	Approximate Depth, ft
1	6
2	13
3	25
4	33
5	40
6	47
7	53
8	63
9	72
10	83
11	88
12	97
13	100
14	101
15	106
16	108
17	115
18	118
19	130
20	140
21	144
22	157
23	165
24	179
25	188
26	199

Description

2. The samples received were somewhat variable in appearance. According to the field log received with the core, the rock was identified as pinkish-gray to gray granite and gneissose granite and black basalt.

Specimen Nos. 1, 2, 3, 4, 5, 11, 12, 13, 14, 15, 16, 18, 19, 21, 22, 23, and 25 contained tightly closed fractures; No. 9 contained a vertical open fracture.

<u>Quality and uniformity tests</u>

3. To determine the variations in physical properties within the hole, specific gravity (sp gr), Schmidt number, ultimate compressive strength (comp strg), and compressional wave velocity (comp wave vel) were determined on specimens prepared from representative samples of the received rock. The results of these tests are given below:

	Sample No.	Description	Core Depth ft	Sp Gr	Schmidt No.*	Ultimate Comp Strg, psi	Comp Wave Vel, fps
Tonalite	3	~~Granite~~	25	2.676	--	37,120	16,270
Tonalite	5	~~Granite~~	40	2.716	50.6	18,790	18,760
Biotite Schist	7	~~Basalt~~	53	2.914	--	18,300	17,350
Tonalite	9	~~Granite~~	72	2.667	--	16,170	16,440
Tonalite	12	~~Granite~~	97	2.682	--	23,290	16,200
Tonalite-Biotite Schist Contact	15	~~Basalt~~-	106	2.716	--	4,000	17,320
Biotite Schist	16	~~Basalt~~	108	3.091	58.8	28,640	22,640
Tonalite-Biotite Schist Contact	18	~~Gneissose Granite-Basalt Contact~~	118	2.726	55.5	2,670	17,790
Tonalite	19	~~Gneissose Granite~~	130	2.686	56.5	27,880	15,220
Tonalite	23	~~Gneissose Granite~~	165	2.678	53.9	25,450	15,210
Tonalite	25	~~Gneissose Granite~~	188	2.662	55.5	32,580	15,830
	Average of Specimens Failing Along Fractures, Nos. 15 and 18			2.721	55.5	3,340	17,550
	Average of Specimens Failing with Vertical Splitting (9)			2.752	55.1	25,360	17,[illegible]

* Schmidt hammer test not conducted on several specimens due to possibility of breakage.

4. Two of the specimens tested failed along preexisting, tightly closed, healed fractures at very low stresses. The remainder of the specimens failed by vertical splitting, which appeared to be relatively independent of preexistent fracturing present in many of the test specimens.

Moduli of deformation

5. Representative specimens were selected for dynamic and static moduli of deformation tests. The dynamic moduli were determined by the proposed ASTM method for determination of ultrasonic pulse velocities and elastic constants of rock. The static moduli were computed from theory of elasticity by use of strain measurements taken from electrical resistance strain gages affixed to the specimens, Nos. 3, 16, and 25. Stress-strain curves are given in plates 1, 2, and 3. Specimens 3 and 25 were cycled at 15,000 psi; specimen 16 was cycled at 5000 psi. Results are given below:

Specimen No.	Modulus, psi x 10^6 Young's	Bulk	Shear	Shear Velocity, fps	Poisson's Ratio
		Dynamic Tests			
3	9.4	2.7	5.2	11,950	--
5	7.8	9.0	2.9	8,890	0.36
7	9.1	7.1	3.5	9,480	0.29
9	7.4	5.9	2.8	8,890	0.29
12	7.8	5.3	3.1	9,290	0.26
15	8.5	6.6	3.3	9,520	0.28
16	16.2	13.0	6.3	12,260	0.29
18	7.1	8.1	2.6	8,470	0.35
19	7.2	4.5	2.9	8,960	0.23
23	6.9	4.7	2.8	8,750	0.25
25	7.1	5.2	2.8	8,830	0.27
		Static Tests			
3	10.0	5.2	4.2	--	0.18
16	15.4	9.2	6.3	--	0.22
25	9.8	5.3	4.1	--	0.19

Dynamic Poisson's ratio could not be accurately computed for specimen 3 due to the unusually high shear velocity to compressive velocity ratio. The specimens tested herein were quite brittle, exhibiting only slight hysteresis.

Conclusions

6. The core received for testing from hole PB-CR-2 was somewhat variable in appearance, identified by the field log received with the core as pinkish-gray to gray granite and gneissose granite and black basalt. Most specimens contained tightly closed fractures. Specimens 15 and 18, which contained tightly healed, critically oriented fractures, failed along these fractures at very low ultimate stresses. The remainder of the specimens, except specimen 7 which appeared intact, also contained tightly closed fractures, but failed by vertical splitting, apparently independent of the fracture systems present. Ultimate compressive strengths ranged from 16,000 to 32,000 psi. Specimen 18, a dense basalt, exhibited unusually high velocities and moduli.

Property	Average of Specimens Failing by Vertical Splitting	Average of Specimens Failing Along Preexisting Fractures
Specific Gravity	2.752	2.721
Schmidt Number	55.1	55.5
Compressive Strength, psi	25,360	3,340
Compressional Wave Velocity, fps	17,100	17,550
Static Young's Modulus, psi x 10^6	11.7	--

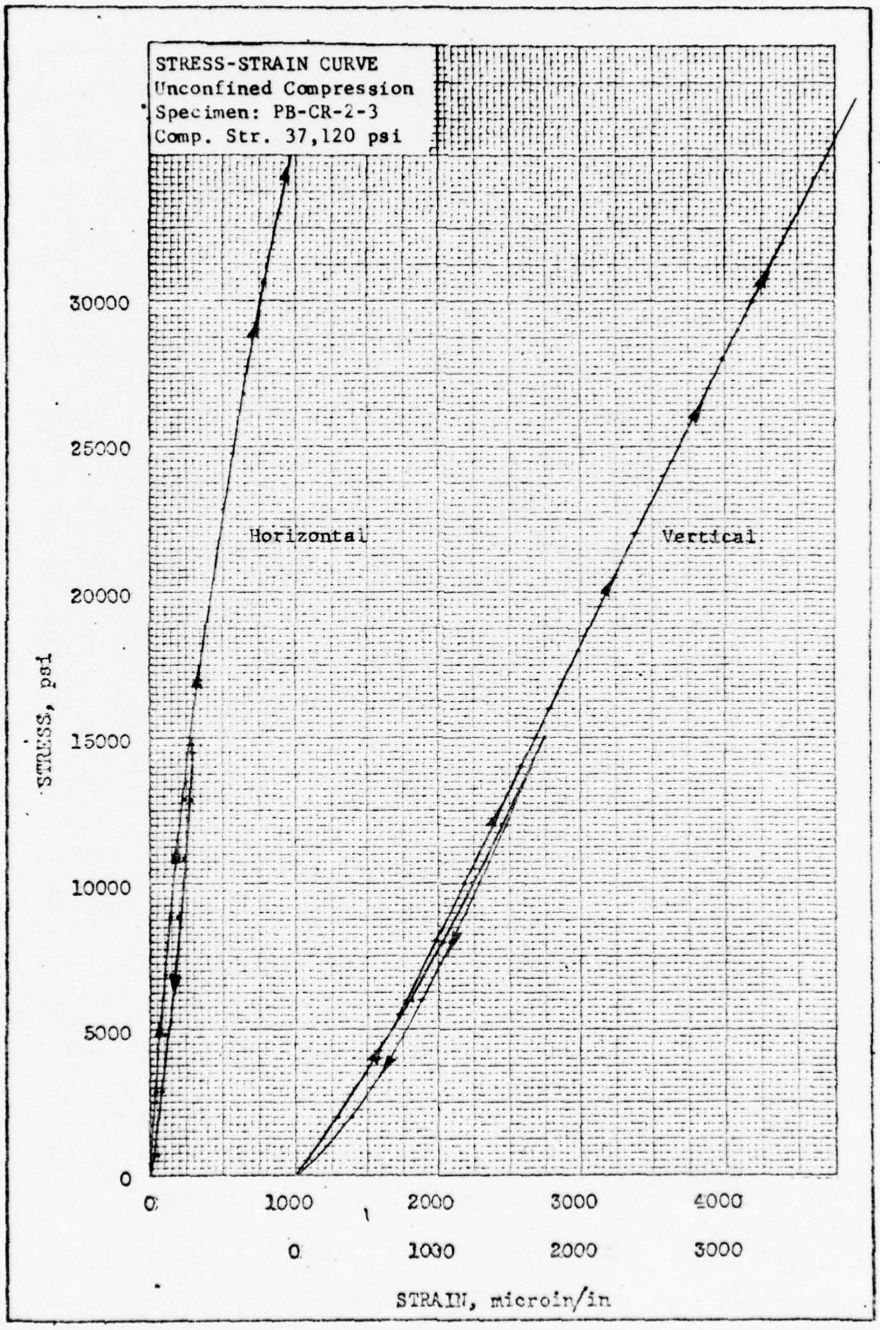

STRESS-STRAIN CURVE
Unconfined Compression
Specimen: PB-CR-2-3
Comp. Str. 37,120 psi
Horizontal
Vertical
STRESS, psi
30000
25000
20000
15000
10000
5000
0
0
1000
2000
3000
4000
0
1000
2000
3000
STRAIN, microin/in

PLATE 1

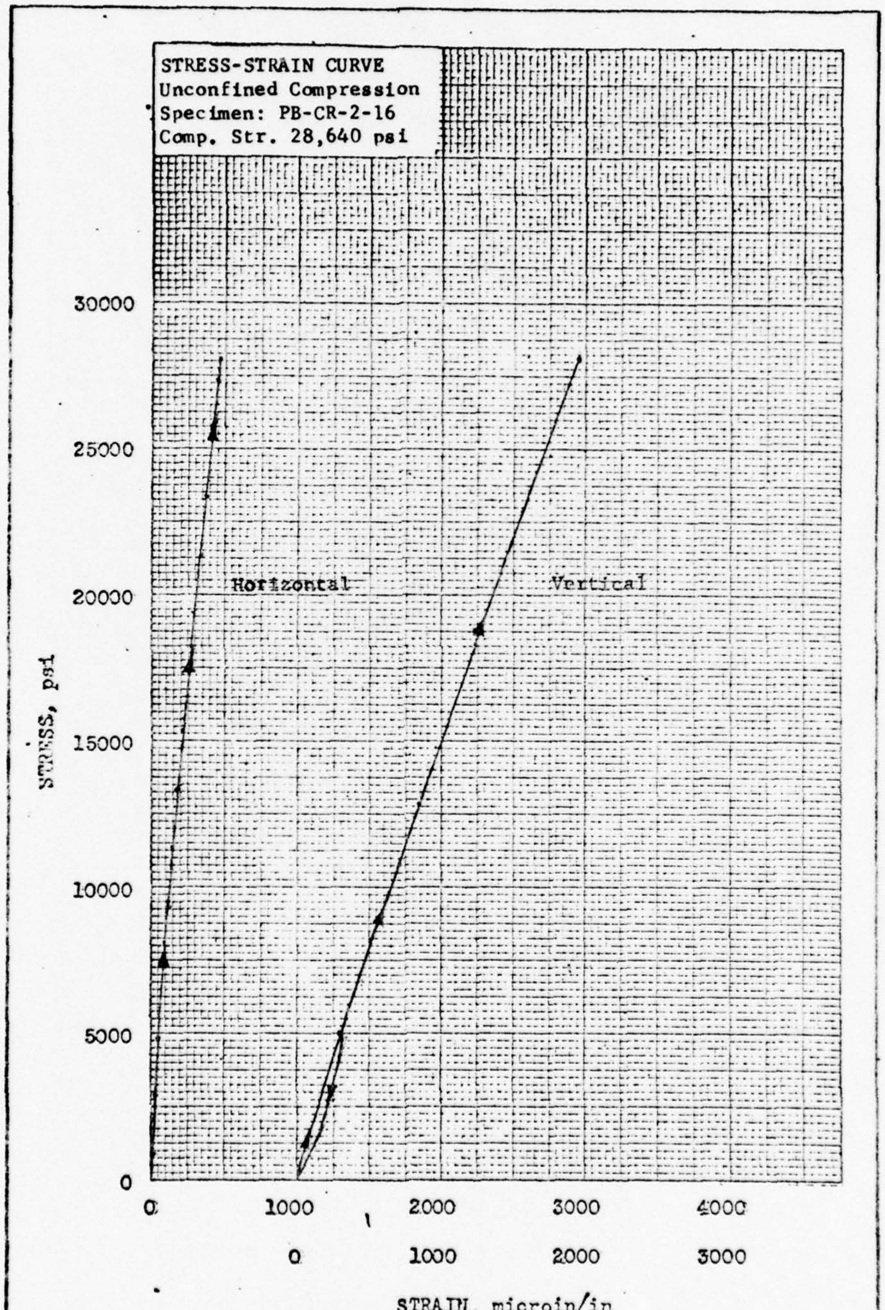

STRESS-STRAIN CURVE
Unconfined Compression
Specimen: PB-CR-2-16
Comp. Str. 28,640 psi
30000
25000
20000
15000
10000
5000
0
STRESS, psi
Horizontal
Vertical
0
1000
2000
3000
4000
0
1000
2000
3000
STRAIN, microin/in

PLATE 2

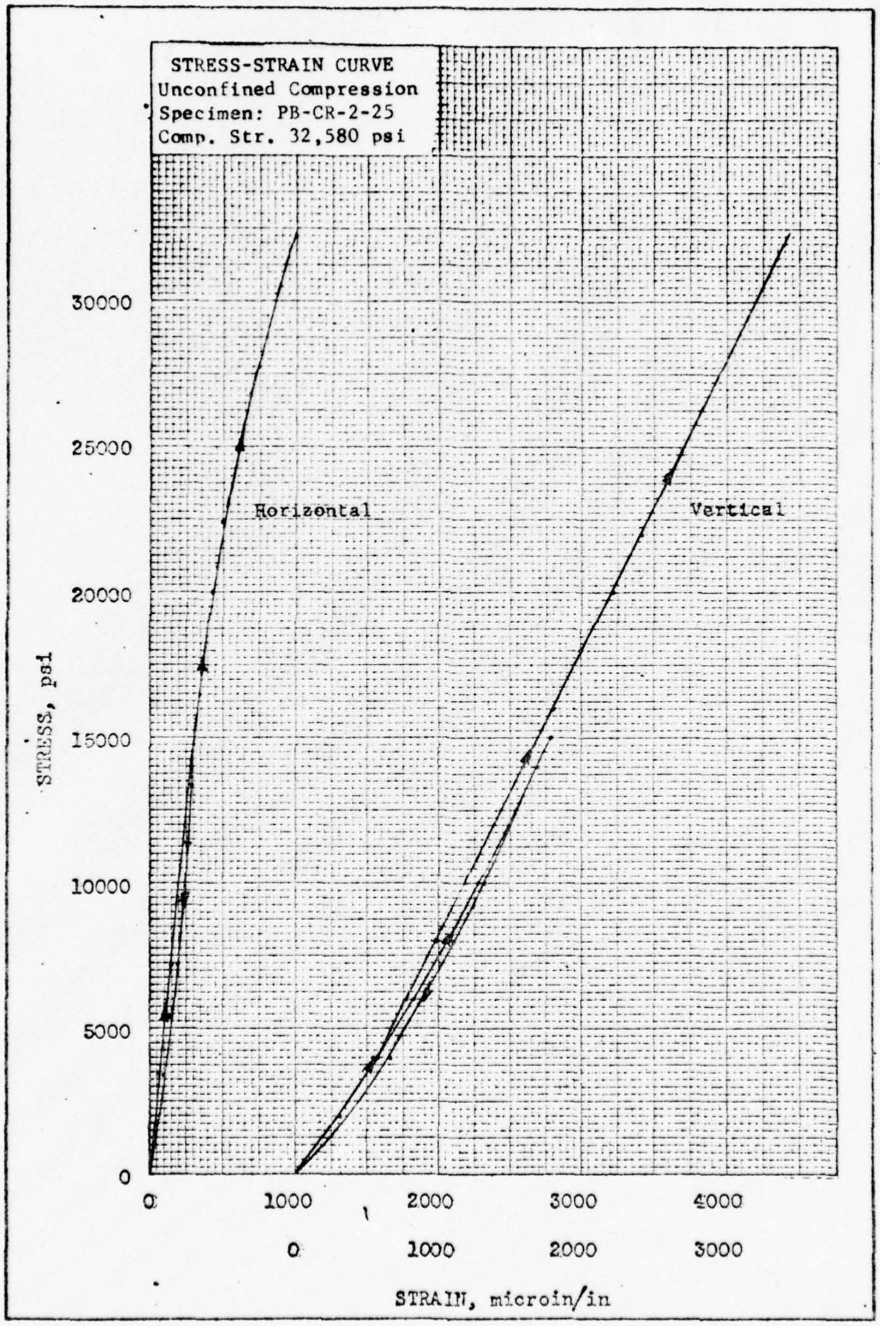

STRESS-STRAIN CURVE
Unconfined Compression
Specimen: PB-CR-2-25
Comp. Str. 32,580 psi
Horizontal
Vertical
STRESS, psi
30000
25000
20000
15000
10000
5000
0
0
1000
2000
3000
4000
0
1000
2000
3000
STRAIN, microin/in

PLATE 3

APPENDIX B

DATA REPORT

Hole PB-CR-10

26 November 1969

Hole Location: Marinette County, Wisconsin

Township 41N, Range 30W, Section 22

Longitude: 45° 36' North

Latitude: 88° 03' West

Core

1. The following core was received on 17 November 1969 for testing:

Core Piece No.	Approximate Depth, ft
1	6
2	14
3	25
4	38
5	47
6	57
7	70
8	82
9	91
10	93
11	99
12	104
13	109
14	114
15	120
16	129
17	133
18	145
19	150
20	160
21	169
22	172
23	176
24	185
25	193

Description

2. The samples received were somewhat variable in appearance. According to the field log received with the core, the rock was identified as pink to pinkish-gray granite and gray to pinkish-gray granodiorite. All specimens except Nos. 1 and 25 contained fractures; several specimens were highly fractured.

Quality and uniformity tests

3. To determine the variations in physical properties within a hole, specific gravity (sp gr), Schmidt number, ultimate compressive strength (comp strg), and compressional wave velocity (comp wave vel) were determined on specimens prepared from representative samples of the received rock. The results of these tests are given below:

	Sample No.	Description	Core Depth ft	Sp Gr	Schmidt No.*	Ultimate Comp Strg, psi	Comp Wave Vel, fps
Tonalite	3	Moderately Fractured	25	2.720	53.7	18,760	19,890
Tonalite	5	Moderately Fractured	47	2.739	55.9	14,210	20,050
Tonalite	8	Moderately Fractured	82	2.700	52.2	11,150	19,470
Tonalite	10	Highly Fractured	93	2.692	--	7,880	17,580
Tonalite	12	Highly Fractured	104	2.651	56.8	5,300	17,670
Schistose Inclusion	13	Highly Fractured	109	2.771	--	1,290	16,360
Tonalite	14	Moderately Fractured	114	2.708	54.8	11,420	19,430
Tonalite	17	Highly Fractured	133	2.702	--	5,730	18,050
Tonalite	19	Moderately Fractured	150	2.737	--	13,730	19,420
Tonalite	22	Moderately Fractured	172	2.711	--	15,850	19,060
Tonalite	23	Moderately Fractured	176	2.704	52.8	14,670	19,200
Tonalite	24	Moderately Fractured	185	2.729	48.5	19,940	19,920
	Average of Highly Fractured Specimens (4)			2.704	56.8	5,300	17,420
	Average of Moderately Fractured Specimens (8)			2.718	53.0	14,970	19,560

* Schmidt hammer test not conducted on several specimens due to possibility of breakage.

4. Some of the core from this hole was highly fractured, i.e., contained many fractures oriented in various directions and frequently intersecting. These specimens were generally representative of the granite recovered from depths 80 to 140 ft as indicated in the core log. The moderately fractured specimens generally contained few fractures, usually not intersecting.

Moduli of deformation

5. Representative specimens were selected for dynamic and static moduli of deformation tests. The dynamic moduli were determined by the proposed ASTM method for determination of ultrasonic pulse velocities and elastic constants of rock. The static moduli were computed from theory of elasticity by use of strain measurements taken from electrical resistance strain gages affixed to the specimens, Nos. 5, 19, and 23. Stress-strain curves are given in plates 1, 2, and 3. The three specimens were cycled at 5000 psi. Results are given below.

Specimen No.	Modulus, psi x 10^6 Young's	Bulk	Shear	Shear Velocity, fps	Poisson's Ratio
		Dynamic Tests			
3	9.4	9.8	3.5	9,790	0.34
5	10.7	9.3	4.1	10,570	0.31
8	7.0	10.4	2.5	8,300	0.39
10	9.0	6.5	3.6	9,910	0.27
12	6.9	7.8	2.5	8,430	0.35
13	6.0	7.1	2.2	7,680	0.36
14	7.1	10.3	2.6	8,370	0.39
17	7.0	8.4	2.6	8,390	0.36
19	8.1	9.9	3.0	8,990	0.36
22	7.4	9.7	2.7	8,580	0.37
23	10.1	8.2	3.9	10,370	0.29
24	7.2	11.1	2.6	8,360	0.39

(Continued)

(Continued)

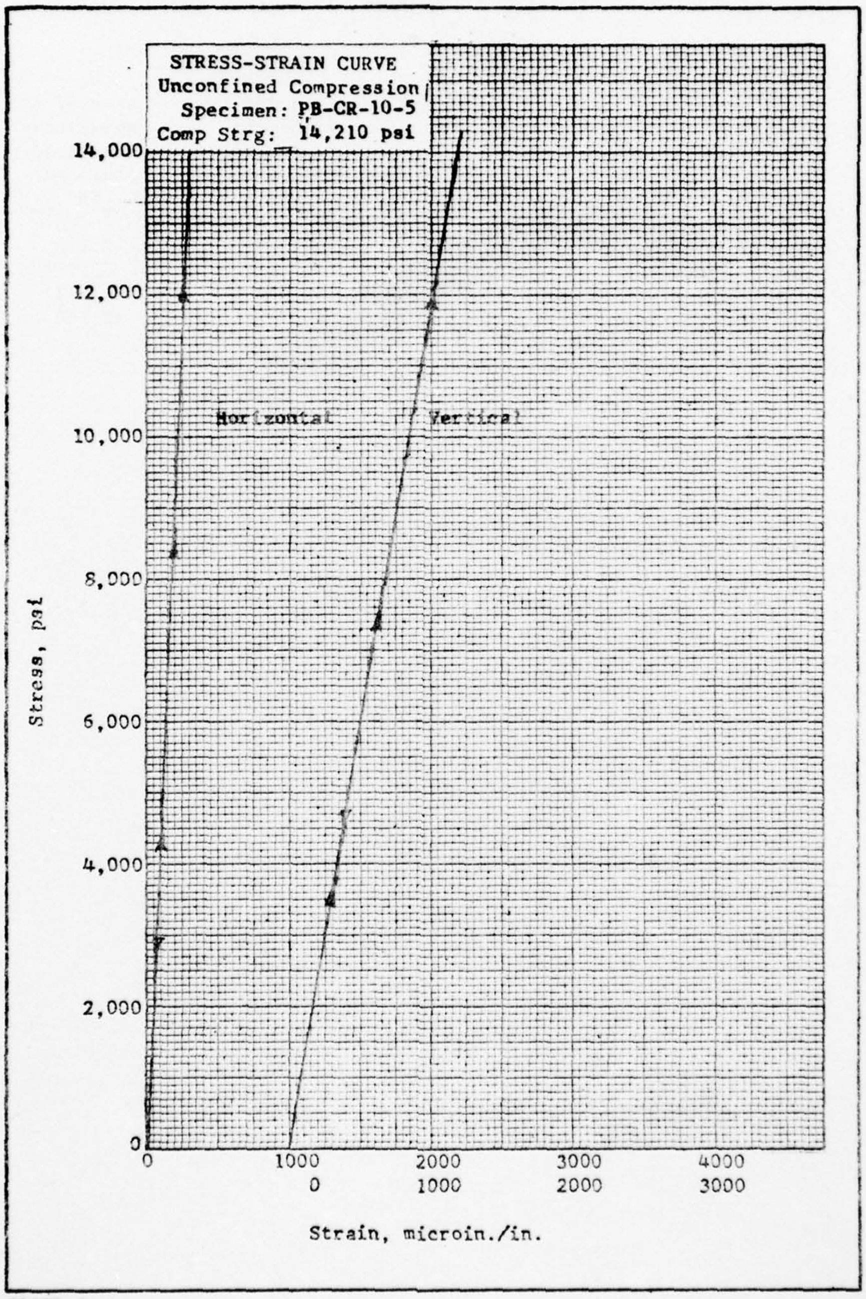
Specimen No.	Modulus, psi x 10^6 Young's	Bulk	Shear	Shear Velocity, fps	Poisson's Ratio
		Static Tests			
5	11.1	7.4	4.4	--	0.25
19	11.8	6.4	4.9	--	0.19
23	10.0	5.7	4.1	--	0.21

6. The moderately fractured material tested herein is quite brittle, exhibiting very little hysteresis. The erratic behavior of the stress-strain curves for specimen No. 19 was apparently due to sudden slippage along fracture surfaces at the higher stress levels.

Conclusions

7. The core received for testing from hole *PB-CR-10* was somewhat variable, identified by the field log received with the core as pink to pinkish-gray granite and gray to pinkish-gray granodiorite. All specimens except Nos. 1 and 25 contained fractures; several specimens were highly fractured. The highly fractured material from this hole was very incompetent, exhibiting compressive strengths ranging from 1300 to 7900 psi. Compressive wave velocities were significantly lower for this material than for the moderately fractured rock, apparently due to the greater degree of fracturing present. The moderately fractured rock was somewhat stronger, exhibiting compressive strengths ranging from 11,000 to 20,000 psi.

Property	Average of Highly Fractured Specimens (4)	Average of Moderately Fractured Specimens (8)
Specific Gravity	2.704	2.718
Schmidt Number	56.8	53.0
Compressive Strength, psi	5,300	14,970
Compressional Wave Velocity, fps	17,420	19,560
Static Young's Modulus, psi x 10^6	--	11.0
Dynamic Young's Modulus, psi x 10^6	7.2	8.4



STRESS-STRAIN CURVE
Unconfined Compression
Specimen: PB-CR-10-5
Comp Strg: 14,210 psi
Stress, psi
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Horizontal
Vertical
0
1000
2000
3000
4000
0
1000
2000
3000
Strain, microin./in.

PLATE 1

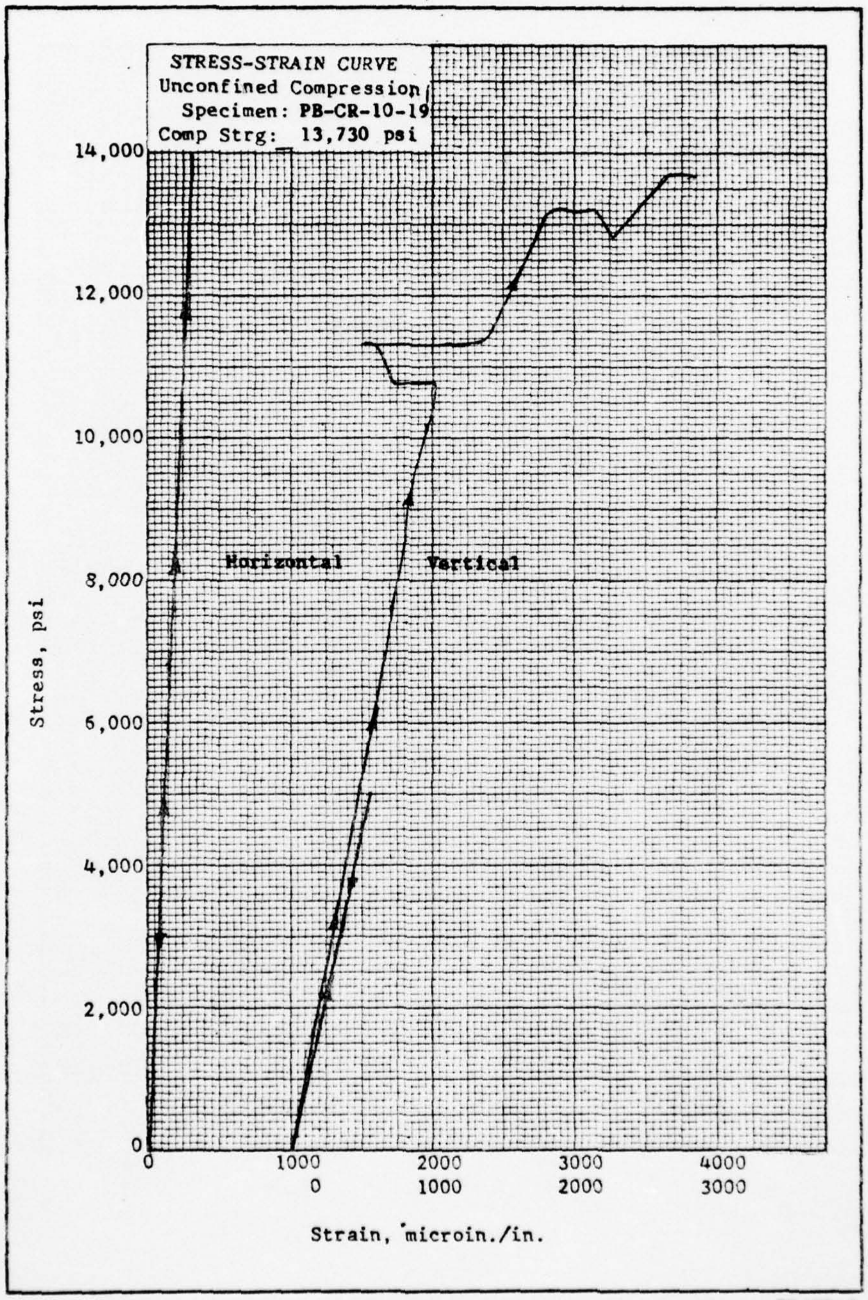

STRESS-STRAIN CURVE
Unconfined Compression
Specimen: PB-CR-10-19
Comp Strg: 13,730 psi
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Stress, psi
Horizontal
Vertical
0
1000
2000
3000
4000
0
1000
2000
3000
Strain, microin./in.

PLATE 2

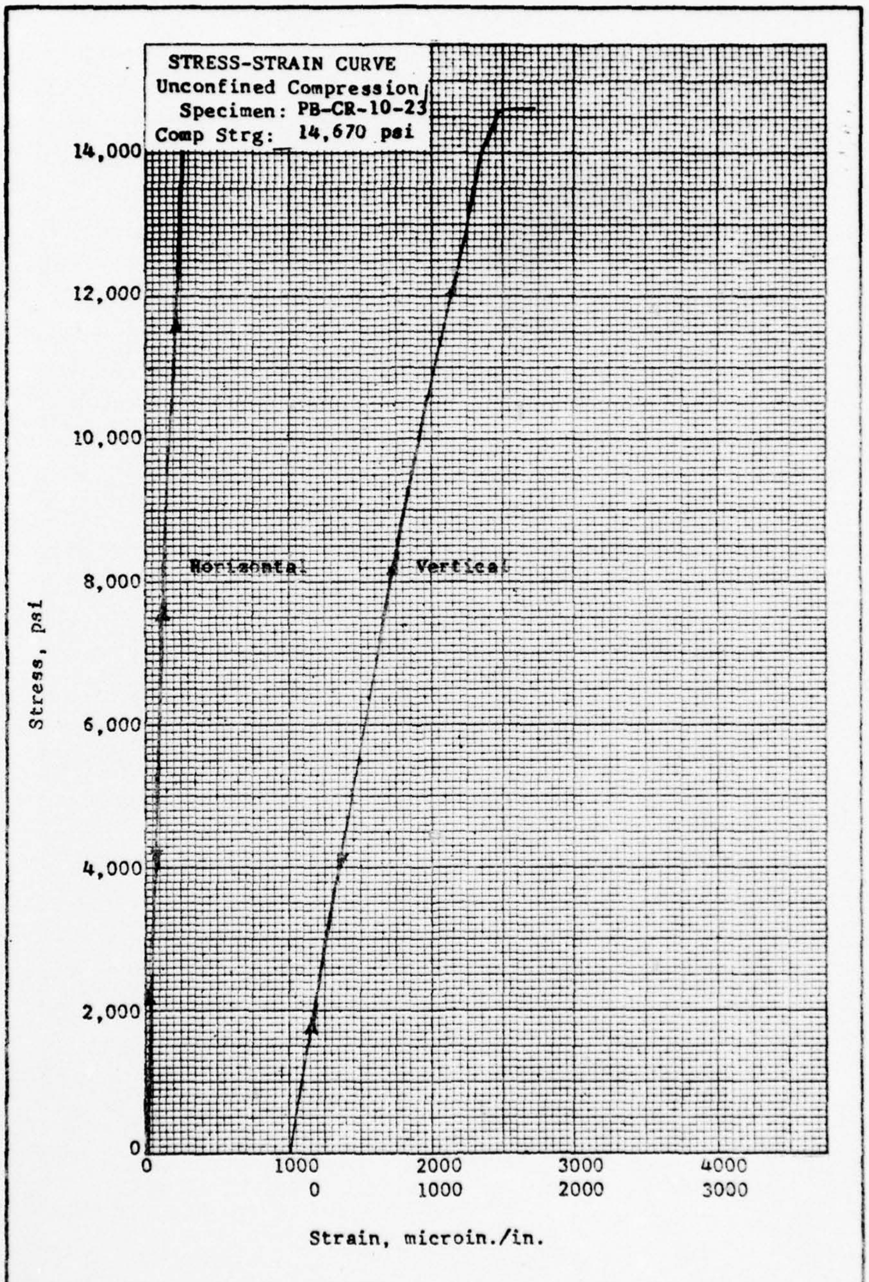

STRESS-STRAIN CURVE
Unconfined Compression
Specimen: PB-CR-10-23
Comp Strg: 14,670 psi
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Stress, psi
Horizontal
Vertical
0
1000
2000
3000
4000
0
1000
2000
3000
Strain, microin./in.

PLATE 3

APPENDIX C

DATA REPORT

Hole PB-CR-16, -16A

26 November 1969

Hole Location: Marinette County, Wisconsin

Township 37N, Range 21E, Section 24

Longitude: 45° 34' North

Latitude: 87° 49' West

Core

1. The following core was received on 12 November 1969 for testing:

PB-CR-16 Core Piece No.	Approximate Depth, ft	PB-CR-16A Core Piece No.	Approximate Depth, ft
1	9	1A	7
2	18	2A	30
3	25	3A	40
		4A	48
		5A	60
		6A	71
		7A	78
		8A	88
		9A	98
		10A	108
		11A	116
		12A	128
		13A	140
		14A	148
		15A	160
		16A	167
		17A	176
		18A	185
		19A	195

Description

2. The samples received were similar in appearance. According to the field logs received with the core, the rock was identified as dark-green greenstone. All specimens contained fractures, many of which were filled with a white substance, probably calcite.

<u>Quality and uniformity tests</u>

3. To determine the variations in physical properties within a hole, specific gravity (sp gr), Schmidt number, ultimate compressive strength (comp strg), and compressional wave velocity (comp wave vel) were determined on specimens prepared from representative samples of the received rock. The results of these tests are given below:

	Sample No.	Core Log Description	Core Depth ft	Sp Gr	Schmidt No.*	Ultimate Comp Strg, psi	Comp Wave Vel, fps
	1A	Greenstone	7	2.888	--	27,270	20,690
	5A	Greenstone	60	2.935	57.8	12,420	22,180
	6A	Greenstone	71	2.871	56.0	6,820	21,750
	8A	Greenstone	88	2.951	57.0	21,910	22,500
Amphibolite Gneiss	10A	Greenstone	108	2.931	52.9	24,240	22,180
	11A	Greenstone	116	2.812	48.6	[illegible],820	21,240
	13A	Greenstone	140	2.848	56.4	5,790	21,670
	16A	Greenstone	167	2.857	51.4	17,210	21,520
	19A	Greenstone	195	2.847	48.3	8,300	20,770
	3	Greenstone	25	2.805	32.7	11,790	18,960

* Schmidt hammer test not conducted on several specimens due to possibility of breakage.

4. The specimens from this hole exhibited considerable variation in uniaxial compressive strength. These results showed no definite trends toward correlation with other physical features such as nature and degree of fracturing and type of failure surface exhibited.

Moduli of deformation

5. Representative specimens were selected for dynamic and static moduli of deformation tests. The dynamic moduli were determined by the proposed ASTM method for determination of ultrasonic pulse velocities and elastic constants of rock. The static moduli were computed from theory of elasticity by use of strain measurements taken from electrical resistance strain gages affixed to the specimens, Nos. 1A, 8A, and 19A. Stress-strain curves are given in plates 1, 2, and 3. The three specimens were cycled at 7500 psi. Results are given below.

Specimen No.	Modulus, psi x 10^6 Young's	Bulk	Shear	Shear Velocity, fps	Poisson's Ratio
		Dynamic Tests			
1A	10.5	11.4	3.9	10,040	0.35
5A	12.6	13.2	4.7	10,930	0.34
6A	12.1	12.2	5.6	10,840	0.33
8A	13.0	13.7	4.9	11,050	0.34
10A	12.9	12.9	4.8	11,090	0.33
11A	10.9	11.6	4.1	11,380	0.34
13A	11.6	12.2	4.3	10,620	0.34
16A	11.7	11.9	4.4	10,700	0.33
19A	11.2	10.8	4.2	10,530	0.33
3	9.0	9.1	3.4	9,460	0.33
		Static Tests			
1A	11.8	8.9	4.6	--	0.28
8A	14.3	10.3	5.6	--	0.27
19A	8.2	5.4	3.3	--	0.25

6. Dynamic moduli for this material were very high and quite uniform. Apparently, the parent rock is itself rather competent, but is drastically weakened by the many calcite-filled fractures present throughout the core. Static tests indicated that the material tested was very brittle. Little hysteresis was exhibited.

Conclusions

7. The core received for testing from holes PB-CR-16 and 16A was relatively uniform, identified by the field log received with the core as dark-green greenstone. All specimens contained fractures, many of which were filled with a white substance, probably calcite. The consistently high wave velocities and dynamic moduli exhibited by this material indicated that the parent rock was relatively competent, but heavy fracturing weakened the parent material drastically. Uniaxial compressive strengths exhibited by the rock were quite variable, ranging from 5000 to 27,000 psi. Compressive strengths showed no apparent correlation with other parameters such as nature and degree of fracturing.

Property	Physical Test Results
Specific Gravity (Avg)	2.874
Schmidt Number (Avg)	51.2
Compressive Strength, psi (Range)	5,790-27,270
Compressional Wave Velocity, fps (Avg)	21,350
Static Young's Modulus, psi x 10^6 (Avg)	11.4

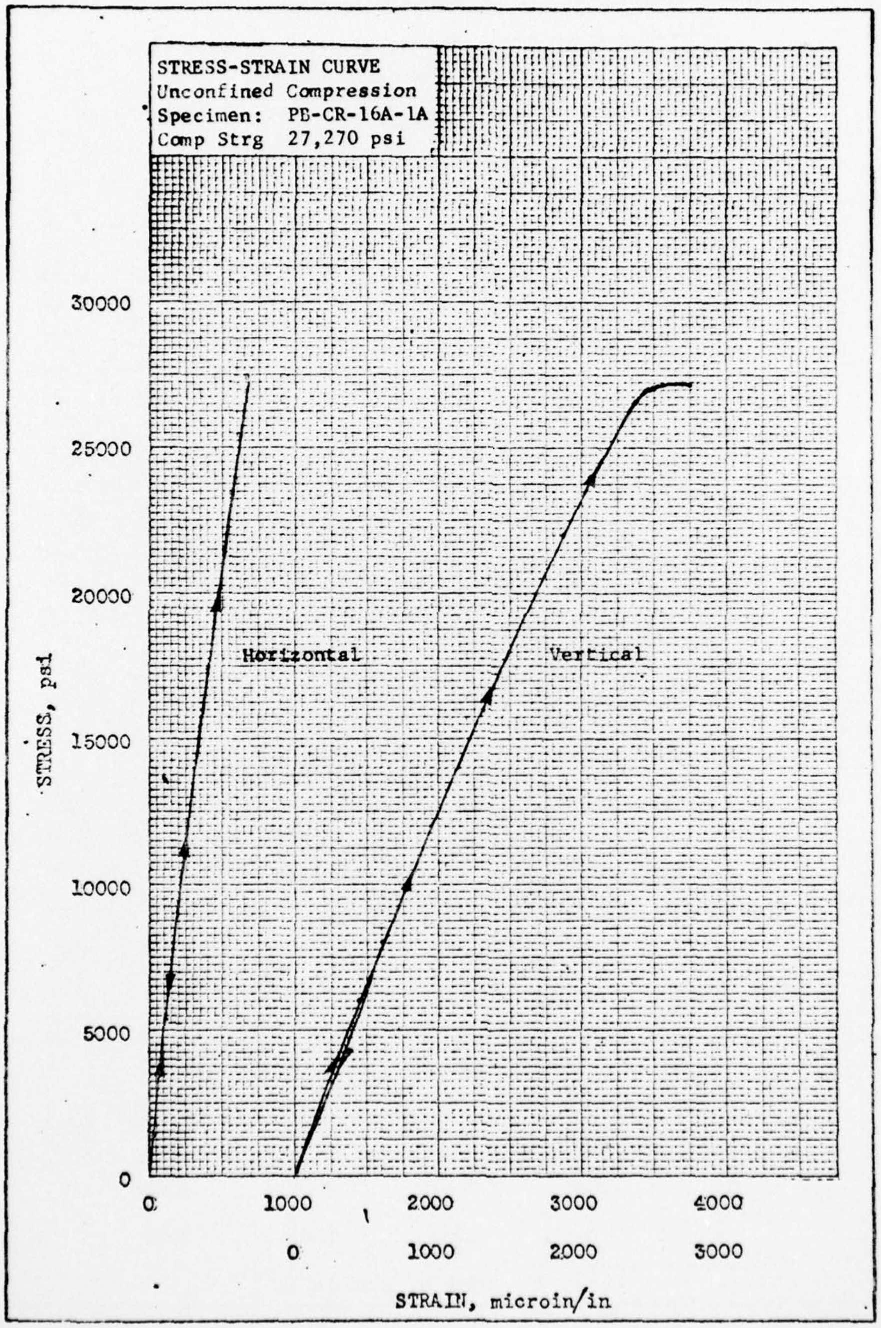

STRESS-STRAIN CURVE
Unconfined Compression
Specimen: PB-CR-16A-1A
Comp Strg 27,270 psi
30000
25000
20000
15000
10000
5000
0
STRESS, psi
Horizontal
Vertical
0
1000
2000
3000
4000
0
1000
2000
3000
STRAIN, microin/in

PLATE 1

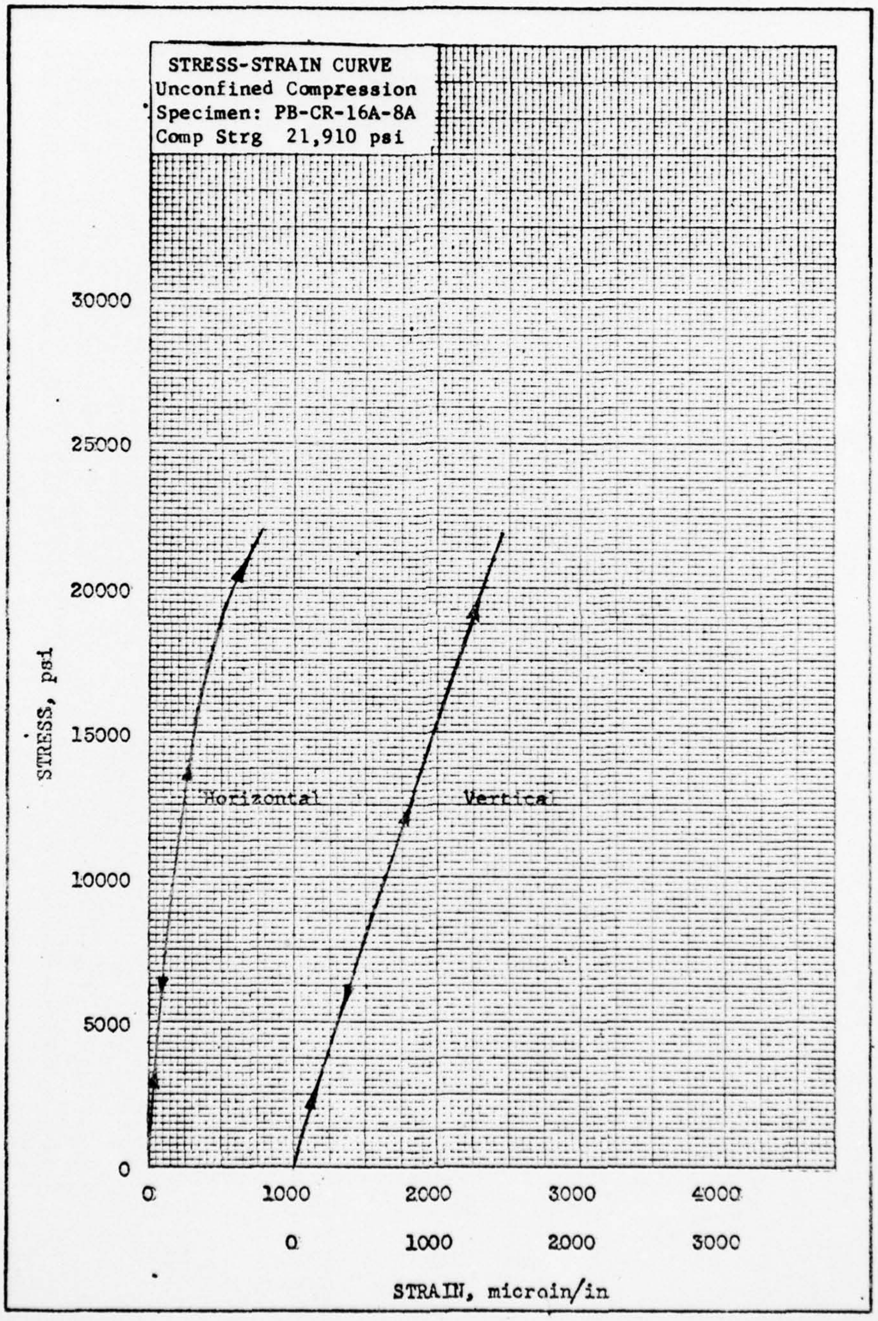
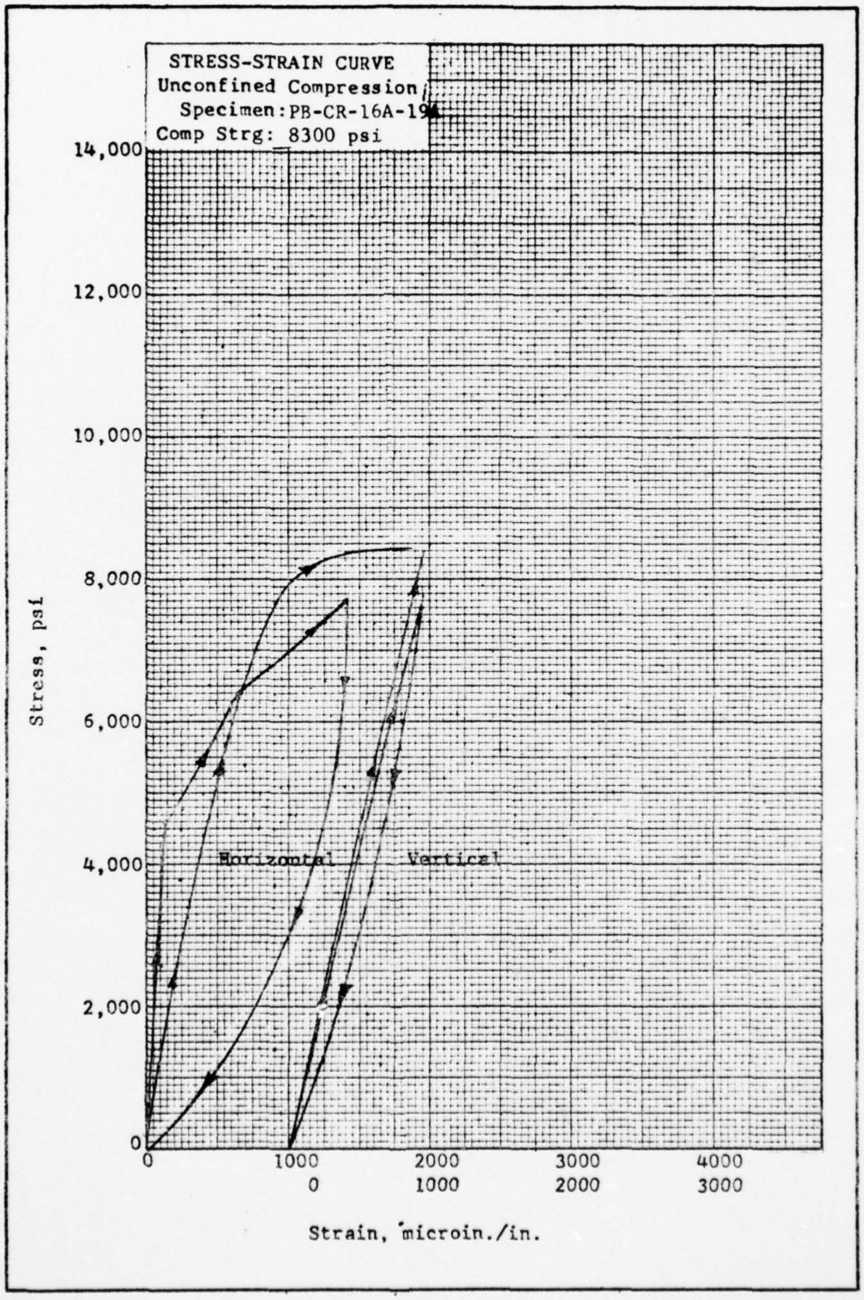

STRESS-STRAIN CURVE
Unconfined Compression
Specimen: PB-CR-16A-8A
Comp Strg 21,910 psi
STRESS, psi
30000
25000
20000
15000
10000
5000
0
Horizontal
Vertical
0
1000
2000
3000
4000
0
1000
2000
3000
STRAIN, microin/in

PLATE 2



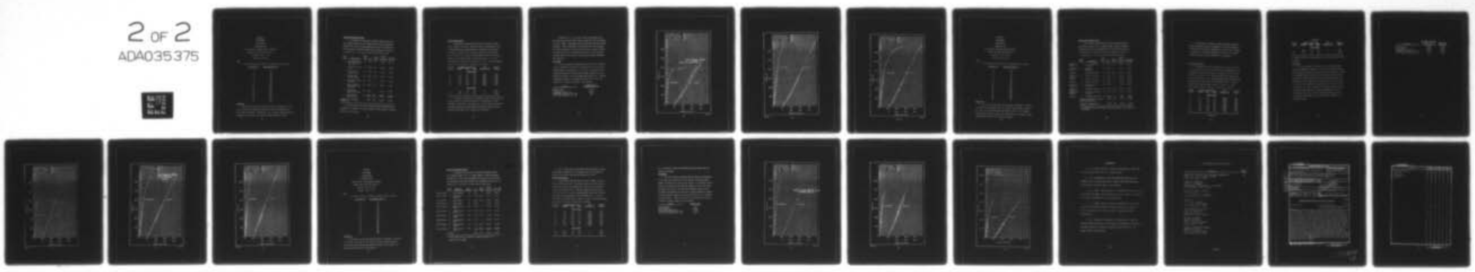
STRESS-STRAIN CURVE
Unconfined Compression
Specimen: PB-CR-16A-19
Comp Strg: 8300 psi
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Stress, psi
Horizontal
Vertical
0
1000
2000
3000
4000
0
1000
2000
3000
Strain, microin./in.

PLATE 3

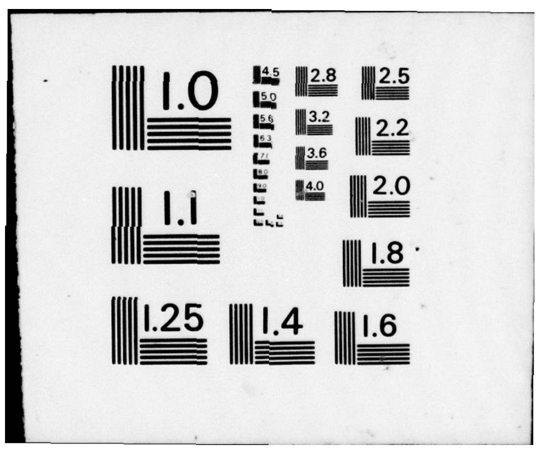
AD-A035 375 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MISS F/G 8/7
TESTS OF ROCK CORES, PEMBINE STUDY AREA, MICHIGAN AND WISCONSIN--ETC(U)
AUG 70 R W CRISP

UNCLASSIFIED WES-MP-C-70-14 NL

2 OF 2
ADA035375



END
DATE
FILMED
3 - 77


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
6.3

APPENDIX D

DATA REPORT

Hole PB-CR-20

26 November 1969

Hole Location: Marinette County, Wisconsin

Township 35N, Range 20E, Section 10

Longitude: 45° 31' North

Latitude: 88° West

Core

1. The following core was received on 7 November 1969 for testing:

Core Piece No.	Approximate Depth, ft
1	5
2	15
3	29
4	39
5	48
6	58
7	67
8	77
9	88
10	98
11	108
12	118
13	128
14	135
15	144
16	150
17	152
18	162
19	172
20	183
21	193
22	199

Description

2. The samples received were relatively uniform in appearance. According to the field log received with the core, the rock was identified as pink to dark-gray granite. Specimen Nos. 1, 2, 14, and 19 contained fractures. Considerable variation in grain size was present throughout the core.

Quality and uniformity tests

3. To determine the variations in physical properties within a hole, specific gravity (sp gr), Schmidt number, ultimate compressive strength (comp strg), and compressional wave velocity (comp wave vel) were determined on specimens prepared from representative samples of the received rock. The results of these tests are given below:

Sample No.	Description	Core Depth ft	Sp Gr	Schmidt No.	Ultimate Comp Strg, psi	Comp Wave Vel, fps
2	Fractured Pinkish-Gray Granite, Contact Zone	15	2.676	55.2	24,240	16,610
4	Light-Gray Granite Intact	39	2.683	51.0	38,180	16,990
7	Pinkish-Gray Granite, Intact	67	2.658	59.3	31,820	17,200
10	Pinkish-Gray Granite, Intact	98	2.661	59.4	31,670	17,730
14	Light-Gray Granite Fractured	135	2.704	--	33,330	17,350
17	Gray to Pinkish-Gray Granite, Contact Zone	152	2.703	55.3	38,480	17,290
19	Pinkish-Gray Granite, Fractured	172	2.653	--	32,730	17,720
21	Pinkish-Gray Granite, Intact	193	2.657	57.6	33,030	17,560
Average of All Specimens Tested (8)			2.674	56.3	32,940	17,310

4. Schmidt hammer test was not conducted on several specimens due to possibility of breakage. The results indicate a very competent, relatively uniform rock in this hole.

Moduli of deformation

5. Representative specimens were selected for dynamic and static moduli of deformation tests. The dynamic moduli were determined by the proposed ASTM method for determination of ultrasonic pulse velocities and elastic constants of rock. The static moduli were computed from theory of elasticity by use of strain measurements taken from electrical resistance strain gages affixed to the specimens, Nos. 2, 4, and 21. Stress-strain curves are given in plates 1, 2, and 3. The three specimens were cycled at 20,000 psi. Results are given below.

Specimen No.	Modulus, psi x 10^6 Young's	Bulk	Shear	Shear Velocity, fps	Poisson's Ratio
		Dynamic Tests			
2	5.9	7.1	2.2	7750	0.36
4	7.8	6.4	3.0	9120	0.30
7	7.9	6.5	3.0	9220	0.30
10	6.8	7.9	2.5	8350	0.36
14	8.8	6.3	3.5	9790	0.27
17	8.3	6.6	3.2	9420	0.29
19	6.6	8.0	2.4	8260	0.36
21	6.4	7.9	2.3	8090	0.37
		Static Tests			
2	9.6	5.4	4.0	--	0.21
4	9.8	5.3	4.1	--	0.19
21	13.9	8.5	5.6	--	0.23

6. The material tested herein is apparently rather brittle, exhibiting little hysteresis. The erratic behavior of the stress-strain curves exhibited by specimen No. 2 was possibly due to the location of the strain gages over preexisting fractures along which sudden slippage occurred; the strain gages failed prior to failure of the specimen.

7. Specimen Nos. 2, 10, 19, and 21 exhibited noticeably lower shear wave velocities and higher Poisson's ratios than did the remainder of the core tested. Compressive wave velocities were relatively uniform throughout. Further investigation revealed that these four specimens were coarser grained and contained more fracturing, indicating possibly that shear velocities were detrimentally affected to a greater degree by larger grain size and physical discontinuities than were compressive wave velocities.

Conclusions

8. The core received for testing from hole PB-CR-20 was relatively uniform, identified by the field log received with the core as pink to dark-gray granite. Specimen Nos. 1, 2, 14, and 19 contained fractures. Considerable variation in grain size was present throughout the core. Physical test results for the core tested were rather uniform. Uniaxial compressive strengths, which ranged from 24,000 to 38,000 psi, were indicative of the general competence of this material.

Property	Average of All Specimens Tested (8)
Specific Gravity	2.674
Schmidt Number	56.3
Compressive Strength, psi	32,940
Compressional Wave Velocity, fps	17,310
Static Young's Modulus, psi x 10^6	11.1

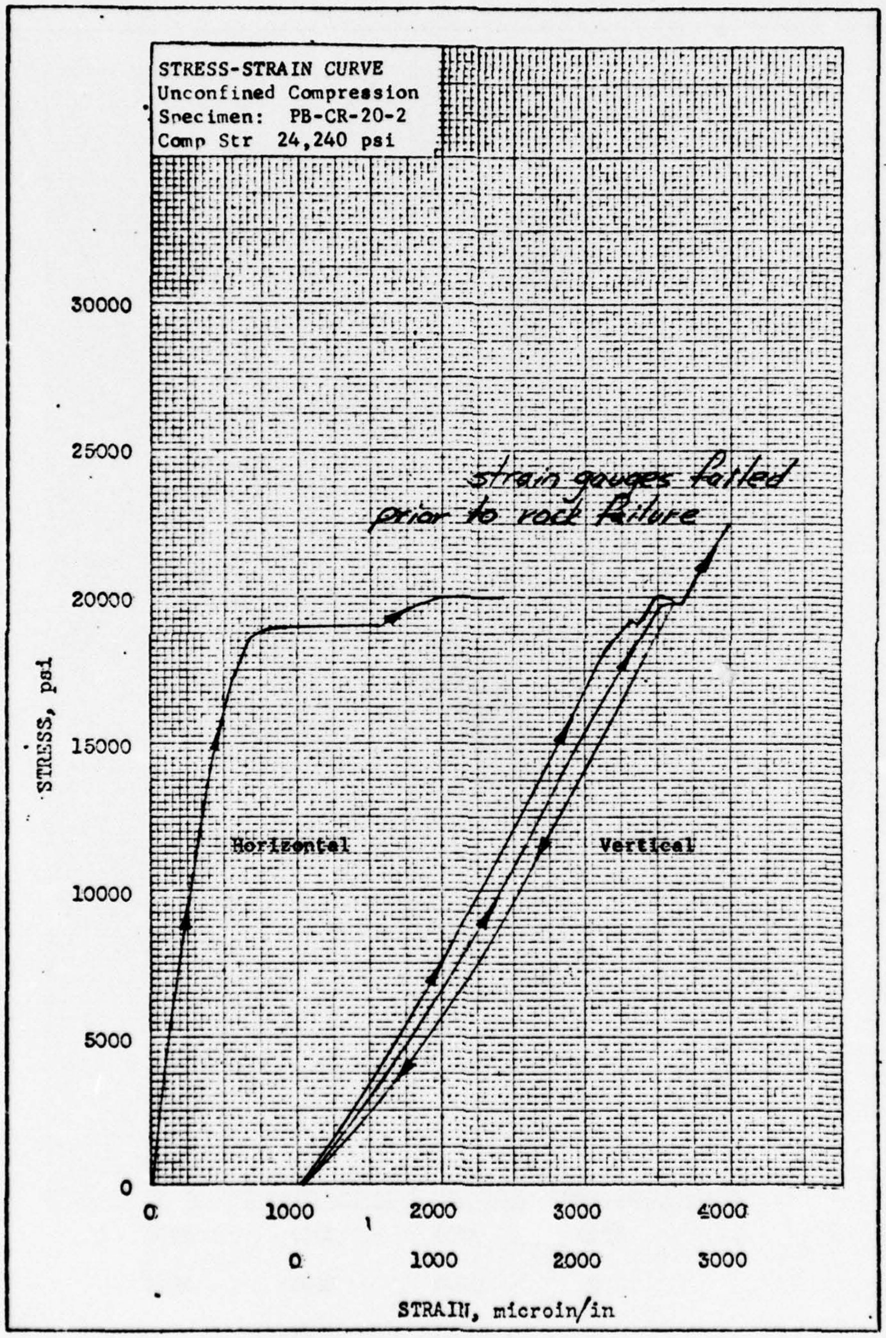

STRESS-STRAIN CURVE
Unconfined Compression
Specimen: PB-CR-20-2
Comp Str 24,240 psi
strain gauges failed prior to rock failure
Horizontal
Vertical
STRESS, psi
0
5000
10000
15000
20000
25000
30000
0
1000
2000
3000
4000
0
1000
2000
3000
STRAIN, microin/in

PLATE 1

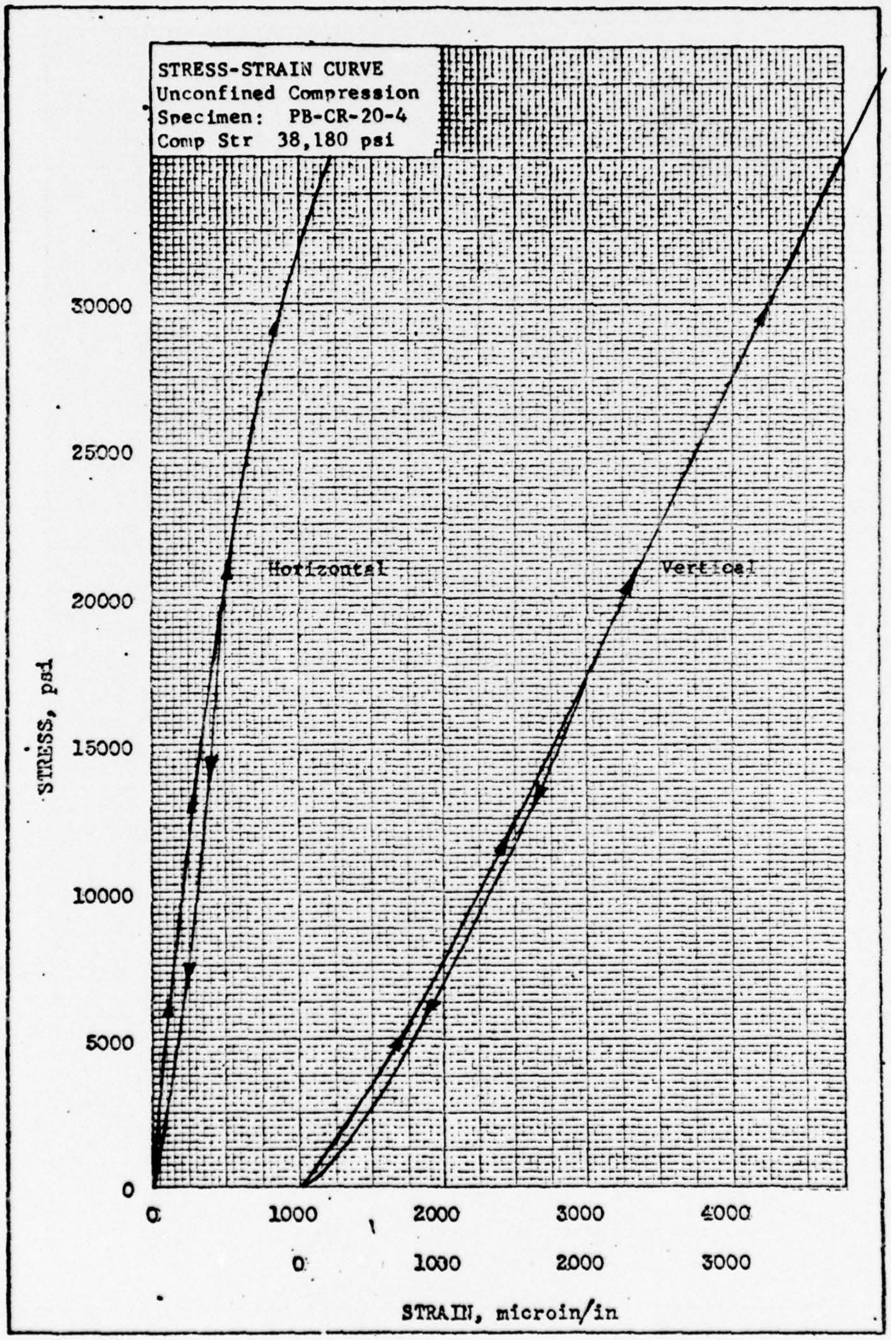
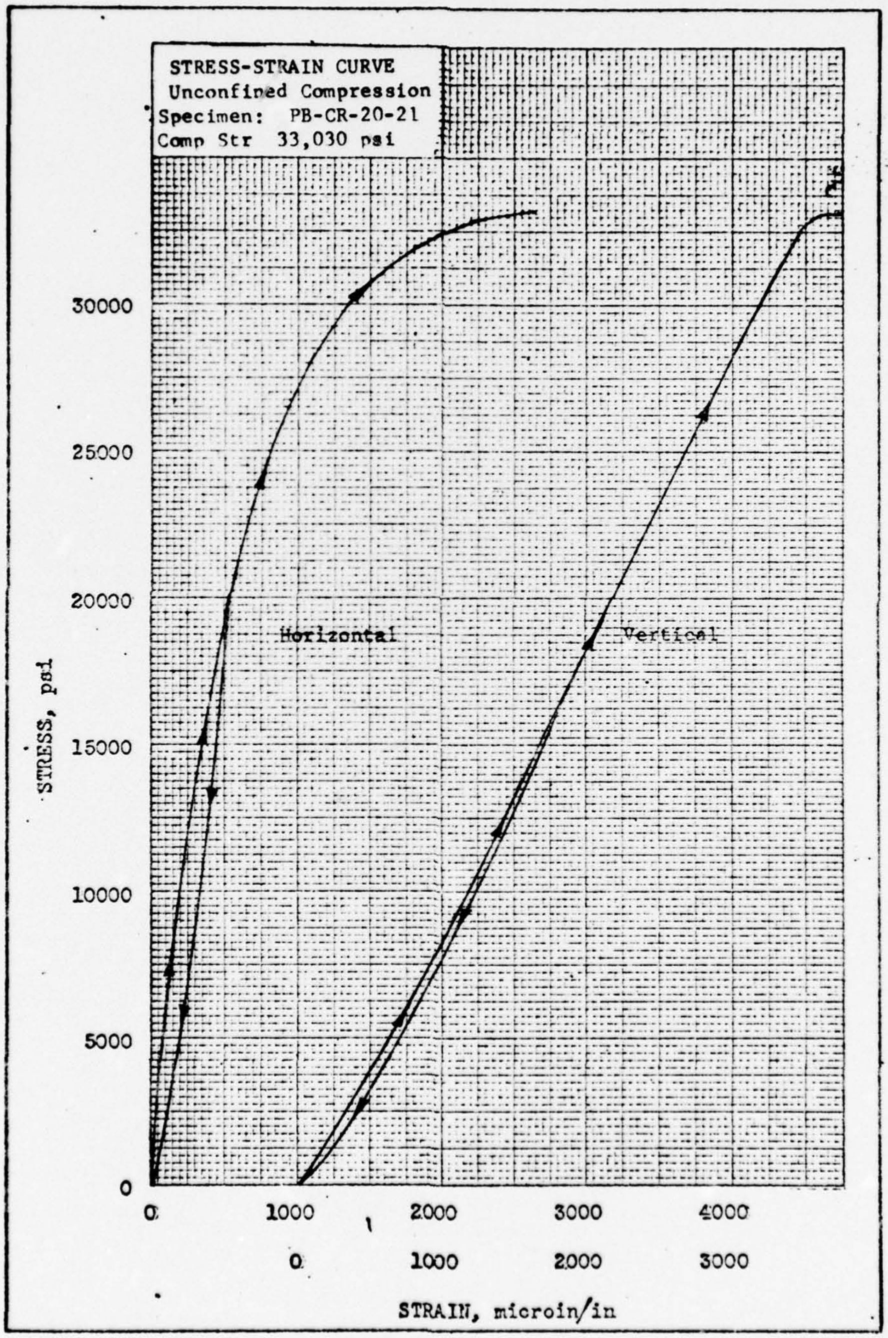

STRESS-STRAIN CURVE
Unconfined Compression
Specimen: PB-CR-20-4
Comp Str 38,180 psi
Horizontal
Vertical
STRESS, psi
0
5000
10000
15000
20000
25000
30000
0
1000
2000
3000
4000
0
1000
2000
3000
STRAIN, microin/in

PLATE 2



STRESS-STRAIN CURVE
Unconfined Compression
Specimen: PB-CR-20-21
Comp Str 33,030 psi
STRESS, psi
30000
25000
20000
15000
10000
5000
0
Horizontal
Vertical
0
1000
2000
3000
4000
0
1000
2000
3000
STRAIN, microin/in

PLATE 3

APPENDIX E

DATA REPORT

Hole PB-CR-27

25 November 1969

Hole Location: Marinette County, Wisconsin

Township 34N, Range 19E, Section 20

Longitude: 45° 24' North

Latitude: 88° 09' West

Core

1. The following core was received on 7 November 1969 for testing:

Core Piece No.	Approximate Depth, ft
1	23
2	35
3	46
4	54
5	59
6	71
7	76
8	87
9	95
10	104
11	113
12	122
13	133
14	145
15	156
16	164
17	173
18	185
19	189
20	193
21	197

Description

2. The samples received were rather variable in appearance. According to the field log received with the core, the rock was identified as mottled red, black, and white granite and black migmatic hornfels. All specimens contained fractures, most of which were tightly closed. The fractures present in specimen Nos. 4 and 19 were critically oriented.

Quality and uniformity tests

3. To determine the variations in physical properties within a hole, specific gravity (sp gr), Schmidt number, ultimate compressive strength (comp strg), and compressional wave velocity (comp wave vel) were determined on specimens prepared from representative samples of the received rock. The results of these tests are given below:

	Sample No.	Description	Core Depth ft	Sp Gr	Schmidt No.*	Ultimate Comp Strg, psi	Comp Wave Vel, fps
Amphibolite Gneiss	1	Horizontal Fractures	23	2.916	57.3	43,030	20,465
Amphibolite Gneiss	4	Horizontal Fractures	54	2.892	--	21,210	20,950
Tonalite	5	Vertical Fractures	59	2.747	54.6	25,610	18,855
Amphibolite Gneiss	7	Vertical Fractures	76	2.905	51.7	31,210	20,615
Tonalite	8	Vertical Fractures	87	2.739	--	28,480	19,225
Tonalite	12	Vertical Fractures	122	2.755	--	36,970	18,830
Amphibolite Gneiss	13	Contains Wavey Inclusion	133	2.828	--	27,120	19,510
Amphibolite Gneiss	17	Horizontal Fractures	173	2.908	52.1	36,360	20,815
Amphibolite Gneiss	19	Critically Oriented Fracture	189	2.925	60.0	3,330	21,315
Tonalite	20	Horizontal Fractures	193	2.673	--	25,000	17,455
	Specimens Containing Critically Oriented Fractures (1)			2.925	60.0	3,330	21,315
	Remainder of Specimens (9)			2.808	53.9	30,550	19,640

* Schmidt hammer test not conducted on several specimens due to possibility of breakage.

4. Specimen No. 19 contained critically oriented fractures and failed along these fractures. Examination of the failure surfaces indicated that the failure in specimen No. 19 occurred in the fracture filler material, a possible explaination for the very low ultimate uniaxial compressive strength exhibited by this specimen.

Moduli of deformation

5. Representative specimens were selected for dynamic and static moduli of deformation tests. The dynamic moduli were determined by the proposed ASTM method for determination of ultrasonic pulse velocities and elastic constants of rock. The static moduli were computed from theory of elasticity by use of strain measurements taken from electrical resistance strain gages affixed to the specimens, Nos. 4, 12, and 17. Stress-strain curves are given in plates 1, 2, and 3. The three specimens were cycled at 20,000 psi. Results are given below.

Specimen No.	Modulus, psi x 10^6			Shear Velocity, fps	Poisson's Ratio
	Young's	Bulk	Shear		
		Dynamic Tests			
1	12.2	10.1	4.7	10,960	0.30
4	11.3	11.4	4.2	10,440	0.33
5	7.9	9.3	2.9	8,870	0.36
7	9.9	9.9	3.6	9,650	0.36
8	7.3	7.3	2.6	8,470	0.38
12	7.9	7.9	2.9	8,830	0.36
13	8.8	10.6	3.3	9,250	0.36
17	11.9	10.9	4.5	10,740	0.32
19	12.8	11.3	4.9	11,140	0.31
20	5.6	8.2	2.0	7,520	0.39

(Continued)

(Continued)

Specimen No.	Modulus, psi x 10^6 Young's	Bulk	Shear	Shear Velocity, fps	Poisson's Ratio
		Static Tests			
4	13.5	9.5	5.3	--	0.26
12	11.4	8.0	4.5	--	0.26
17	13.9	9.5	5.5	--	0.26

The material tested herein was generally quite brittle, exhibiting slight hysteresis.

Conclusions

6. The core received for testing from hole PB-CR-27 was rather variable in appearance, identified by the field log received with the core as mottled red, black, and white granite and black migmatic hornfels. All specimens contained fractures, most of which were tightly closed. Physical test results were generally high but somewhat variable. With the exception of two specimens which failed along critically oriented fractures, uniaxial compressive strengths exhibited ranged from 25,000 to 43,000 psi. Of the two specimens failing along fractures, one was considerably weaker (3330 psi). This large difference, since the fractures were inclined at the same angles, was possibly due to the differences in nature and amount of filler material observed on the fracture surfaces.

Property	Specimens Containing Critically Oriented Fractures	Remainder of Specimens
Specific Gravity	2.908	2.809
Schmidt Number	60.0	53.9
Compressive Strength, psi	12,270	31,720
Compressional Wave Velocity, fps	21,130	19,470
Static Young's Modulus, psi x 10^6	13.5	12.6

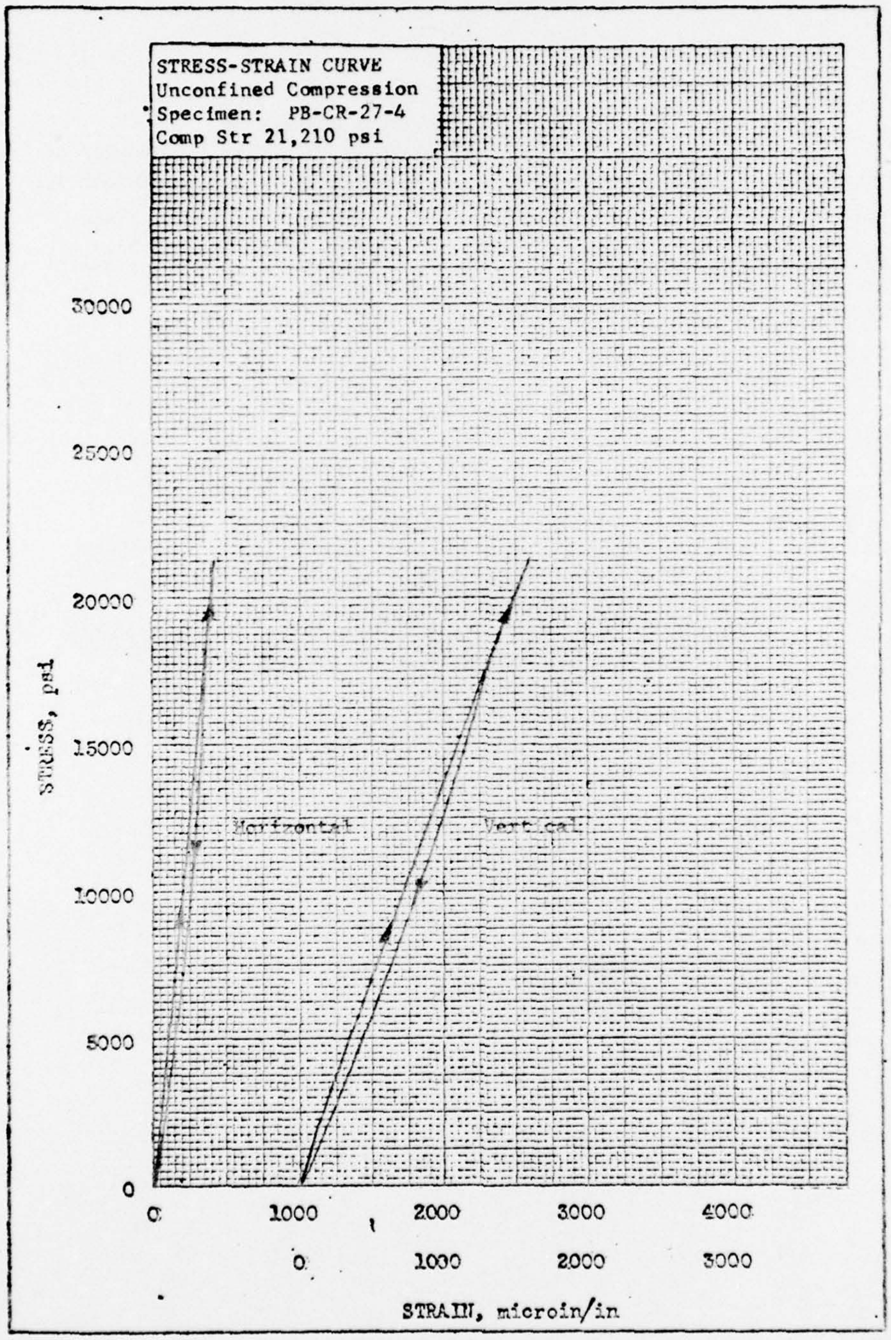

STRESS-STRAIN CURVE
Unconfined Compression
Specimen: PB-CR-27-4
Comp Str 21,210 psi
30000
25000
20000
15000
10000
5000
0
STRESS, psi
Horizontal
Vertical
0
1000
2000
3000
4000
0
1000
2000
3000
STRAIN, microin/in

PLATE 1

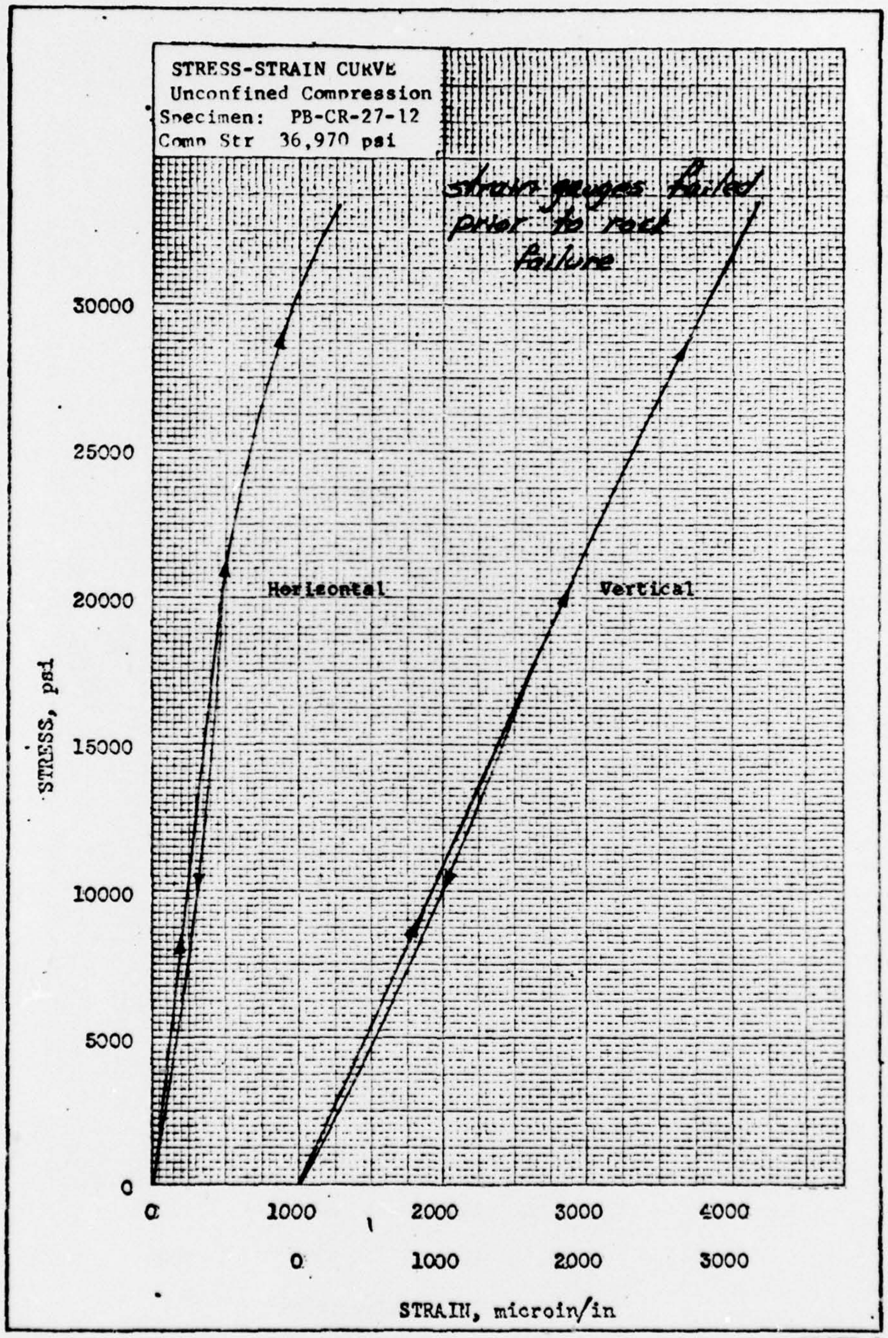

STRESS-STRAIN CURVE
Unconfined Compression
Specimen: PB-CR-27-12
Comp Str 36,970 psi
strain gauges failed prior to rock failure
Horizontal
Vertical
STRESS, psi
0
5000
10000
15000
20000
25000
30000
0
1000
2000
3000
4000
0
1000
2000
3000
STRAIN, microin/in

PLATE 2

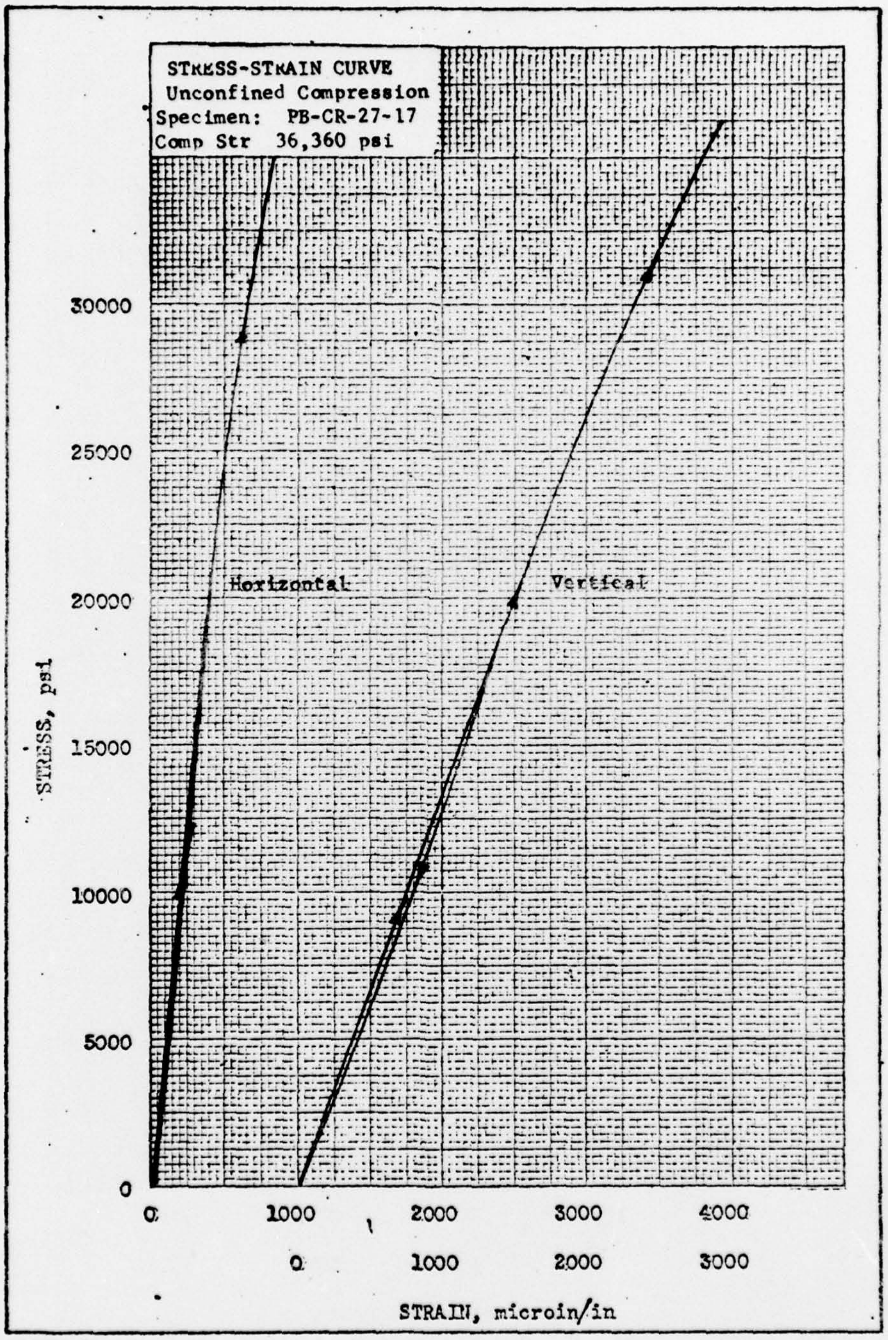

STRESS-STRAIN CURVE
Unconfined Compression
Specimen: PB-CR-27-17
Comp Str 36,360 psi
Horizontal
Vertical
STRESS, psi
30000
25000
20000
15000
10000
5000
0
0
1000
2000
3000
4000
0
1000
2000
3000
STRAIN, microin/in

PLATE 3

APPENDIX F

DATA REPORT

Hole PB-CR-40

25 November 1969

Hole Location: Oconto County, Wisconsin

Township 32N, Range 17E, Section 32

Longitude: 45° 12' North

Latitude: 88° 23' West

Core

1. The following core was received on 7 November 1969 for testing:

Core Piece No.	Approximate Depth, ft
1	4
2	11
3	16
4	21
5	32
6	43
7	55
8	65
9	76
10	86
11	92
12	102
13	113
14	123
15	132
16	144
17	153
18	158
19	167
20	177
21	188
22	198

Description

2. The samples received were somewhat variable in appearance. According to the field log received with the core, the rock was identified as gray to dark gray granite gneiss, augen gneiss, and quartz diorite gneiss. All specimens contained tightly closed fractures.

Quality and uniformity tests

3. To determine the variations in physical properties within a hole, specific gravity (Sp Gr), Schmidt number, ultimate compressive strength (Comp Strg), and compressional wave velocity (Comp Wave Vel) were determined on specimens prepared from representative samples of the received rock. The results of these tests are given below:

	Sample No.	Core Log Description	Core Depth, ft	Sp Gr	Schmidt No.*	Ultimate Comp Strg psi	Comp Wave Vel fps
Biotite Gneiss	4	Granite Gneiss	21	2.734	--	36,890	18,270
Biotite Gneiss	7	Transitional Material	55	2.746	54.6	27,270	19,710
Quartz Gneiss	8	Augen Gneiss	65	3.144	54.2	32,270	21,920
Biotite Gneiss	11	Augen Gneiss	92	2.762	--	25,390	17,910
Biotite Gneiss	12	Quartz Diorite Gneiss	102	2.736	--	24,700	19,120
Biotite Gneiss	15	Quartz Diorite Gneiss	132	2.922	54.9	56,670	22,340
Quartz Gneiss	17	Quartz Diorite Gneiss	153	2.810	57.0	19,090	20,250
Quartz Gneiss	18	Quartz Diorite Gneiss	158	3.133	--	36,820	22,110
Biotite Gneiss	20	Quartz Diorite Gneiss	177	2.735	56.0	42,120	19,230
Biotite Gneiss	21	Quartz Diorite Gneiss	188	2.751	58.5	24,090	18,900
	Averages			2.847	55.9	32,530	19,980

* Schmidt hammer test not conducted on several specimens due to possibility of breakage.

4. The ultimate uniaxial compressive strengths obtained for these rocks varied considerably; this was possibly due to the variation in nature of the tightly closed fractures present in the rock.

Moduli of deformation

5. Representative specimens were selected for dynamic and static moduli of deformation tests. The dynamic moduli were determined by the proposed ASTM method for determination of ultrasonic pulse velocities and elastic constants of rock. The static moduli were computed from theory of elasticity by use of strain measurements taken from electrical resistance strain gages affixed to the specimens, Nos. 8, 12, and 20. Stress-strain curves are given in plates 1, 2, and 3. The three specimens were cycled at 20,000 psi. Results are given below.

Specimen	Modulus, psi x 10^6			Shear	Poisson's
No.	Young's	Bulk	Shear	Velocity, fps	Ratio
		Dynamic Tests			
4	7.5	8.6	2.8	8,670	0.35
7	10.5	9.0	4.0	10,440	0.30
8	15.3	12.5	5.9	11,790	0.30
11	7.8	8.0	2.9	8,870	0.34
12	10.5	8.0	4.1	10,570	0.28
15	13.2	13.0	5.0	11,240	0.33
17	12.5	8.9	4.9	11,430	0.27
18	14.4	13.4	5.4	11,360	0.32
20	8.1	9.6	3.0	8,990	0.36
21	10.0	8.0	3.9	10,260	0.29
		Static Tests			
8	12.3	7.5	5.0	--	0.23
12	11.8	7.2	4.8	--	0.23
20	14.5	9.3	5.9	--	0.24

All of the material tested herein exhibited brittle behavior and had negligible hysteresis.

Conclusions

6. The core received for testing from hole PB-CR-40 was identified by the field log received with the core as gray to dark gray granite gneiss, augen gneiss, and quartz diorite gneiss. All specimens contained tightly closed fractures which generally appeared to have little effect on physical test results. The more dense specimens tended to exhibit the higher compressional wave velocities. Ultimate compressive strengths were quite variable, ranging from 19,000 to 57,000 psi, but all material appeared competent. Dynamic and static moduli were generally very high. A summary of physical properties is given below.

Property	Average Values
Specific Gravity	2.847
Schmidt Number	55.9
Compressive Strength, psi	32,530
Compressional Wave Velocity, fps	19,980
Static Young's Modulus, psi x 10^6	12.9

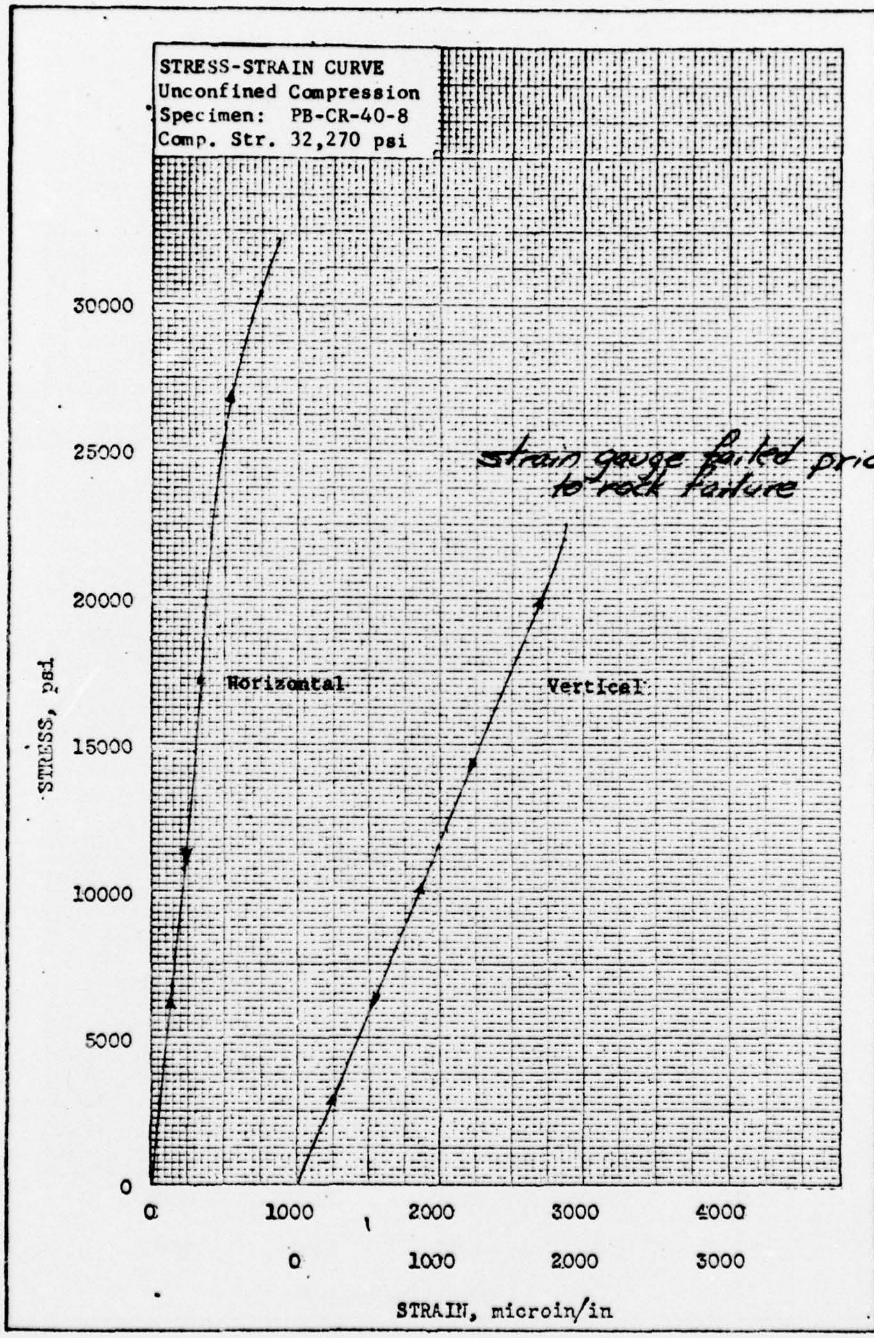

STRESS-STRAIN CURVE
Unconfined Compression
Specimen: PB-CR-40-8
Comp. Str. 32,270 psi
strain gauge failed prior to rock failure
Horizontal
Vertical
STRESS, psi
0
5000
10000
15000
20000
25000
30000
0
1000
2000
3000
4000
0
1000
2000
3000
STRAIN, microin/in

PLATE 1

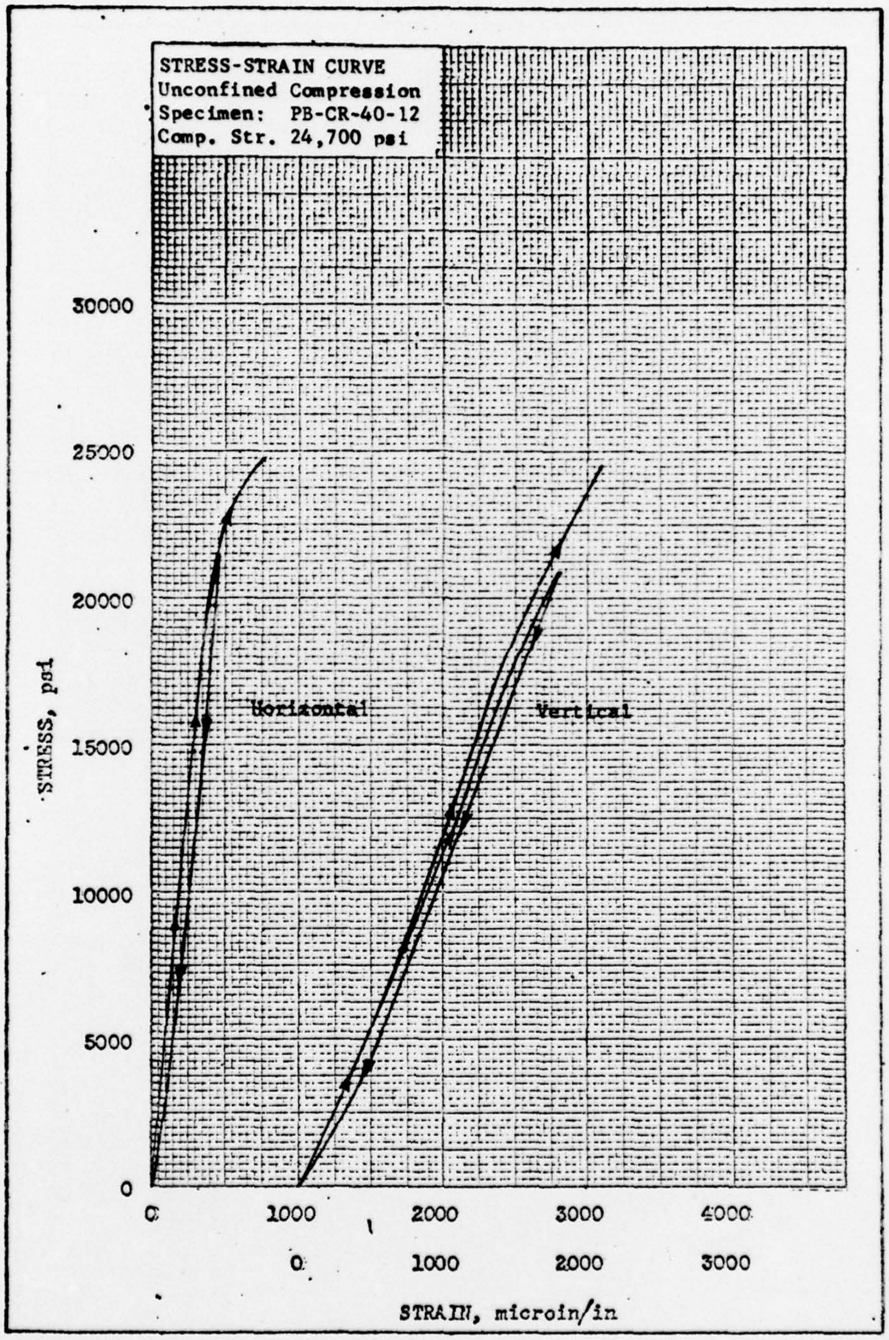

STRESS-STRAIN CURVE
Unconfined Compression
Specimen: PB-CR-40-12
Comp. Str. 24,700 psi
STRESS, psi
30000
25000
20000
15000
10000
5000
0
Horizontal
Vertical
0
1000
2000
3000
4000
0
1000
2000
3000
STRAIN, microin/in

PLATE 2

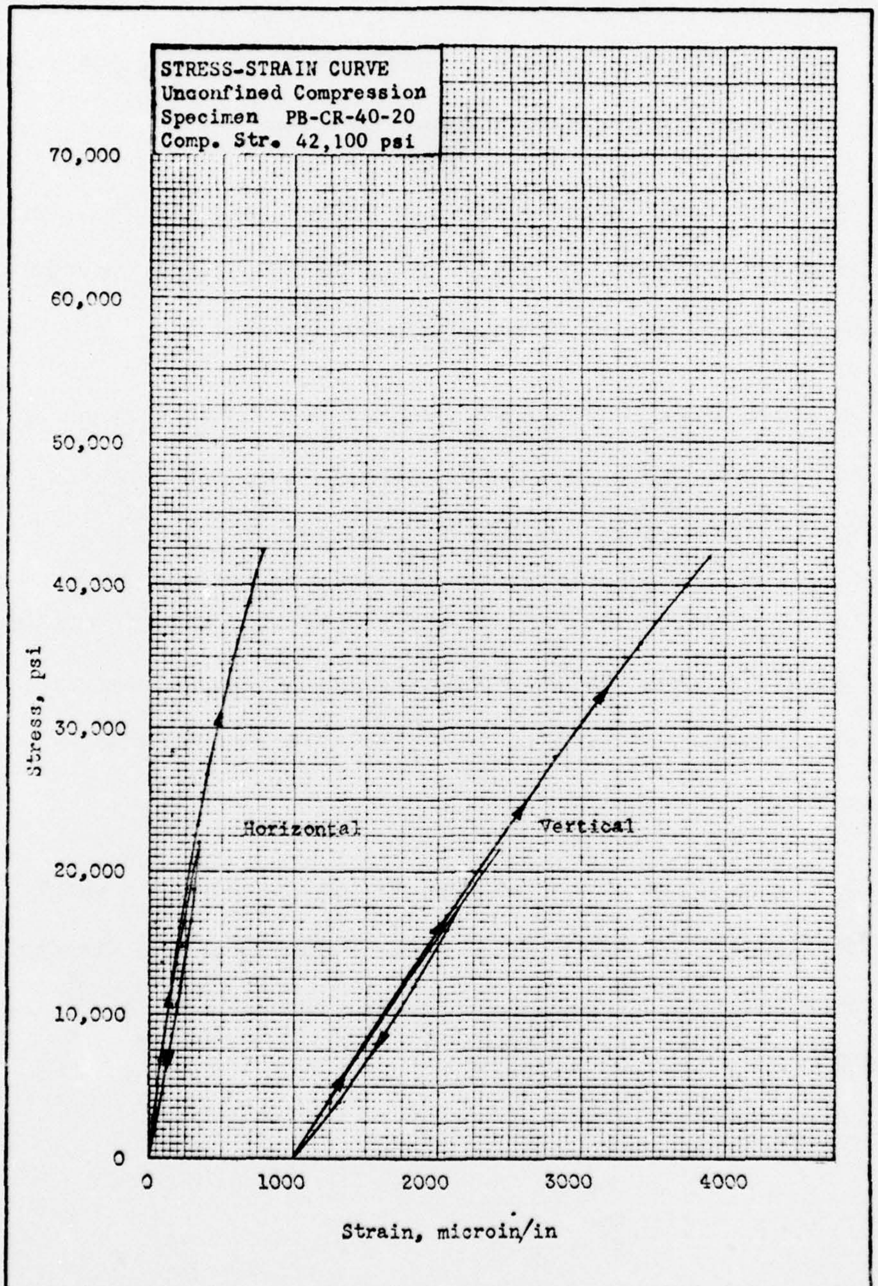

STRESS-STRAIN CURVE
Unconfined Compression
Specimen PB-CR-40-20
Comp. Str. 42,100 psi
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Stress, psi
Horizontal
Vertical
0
1000
2000
3000
4000
Strain, microin/in

PLATE 3

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Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)
U. S. Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP

3. REPORT TITLE
6 TESTS OF ROCK CORES, PEMBINE STUDY AREA, MICHIGAN AND WISCONSIN.

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
9 Final report. Nov 69 - Jun 70,

5. AUTHOR(S) (First name, middle initial, last name)
10 Robert W. Crisp

12 119p.

6. REPORT DATE
11 August 1970

7a. TOTAL NO. OF PAGES
121

7b. NO. OF REFS
5

8a. CONTRACT OR GRANT NO.

b. PROJECT NO.
14 WES-MP-C-70-14

9a. ORIGINATOR'S REPORT NUMBER(S)
Miscellaneous Paper C-70-14

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

Approved for Public Release; Distribution Unlimited

ior

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
Space and Missile Systems Organization
U. S. Air Force Systems Command

13. ABSTRACT

Laboratory tests were conducted on rock core samples received from six core holes in the Pembine Area of Dickinson County, Michigan, and Marinette and Oconto Counties, Wisconsin. Results were used to evaluate the quality and uniformity of the rock to depths of 200 feet below ground surface. The core was identified as predominantly tonalite, granite, amphibolite gneiss, and biotite gneiss, with relatively insignificant quantities of quartz gneiss and biotite schist. Evaluation of the Pembine Area core on a hole-to-hole basis indicates that the granite removed from Hole PB-CR-20 and the biotite and quartz gneiss removed from Hole PB-CR-40 are quite competent materials and should offer good possibilities as competent hard rock media. The tonalite and amphibolite gneiss removed from Hole PB-CR-27 were found to be relatively competent rock, with only one specimen, an amphibolite gneiss, yielding physical test results characteristic of marginal quality rock. Generally, this hole yielded material that should offer some possibility as a competent hard rock medium. Holes PB-CR-2, -10, and -16A generally yielded rock core that exhibited rather varied physical properties. Though much of the rock was relatively competent in quality, several specimens that were removed from depths greater than 50 feet below ground surface in each hole were found to be quite incompetent. The presence of these poor quality materials at depths greater than 50 feet dictates classification of the entire cores as unsuitable, incompetent media. The evaluations and conclusions above were based on somewhat limited data. Therefore, more extensive investigation will be required in order to fully define the individual areas under consideration.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Pembine Area, Mich.-Wis.						
Rock cores						
Rock properties						
Rock tests						